4 Potential of the blockchain in the energy sector

This chapter offers a much more sweeping view of the energy sector which certainly not every reader is familiar with and, as such, may not be captivated by each detail. This chapter is optional for everyone who tends to be more interested in technical questions. In this case, it would be more beneficial to skim the following pages and continue with Chapter 5 where we concentrate on organizational issues during the implementation of blockchain projects.

However, I do recommend to the reader who is less interested in issues of energy or the energy sector to work through the next pages. The art and manner in which energy will move from x-million generators to hundreds of millions of consumers in the future is, due to these participant numbers, already a matter of social significance.

In this Chapter's vision of the energy market in 2030, no more subsidies exist and today's rigid regulations are supposed to give way to a market-based coordination of a flexible energy supply system. Market mechanisms will be largely used to facilitate the interaction between the production, the transmission, and the consumption of electricity. This follows the "invisible hand" of the market rather than the coordination alongside a hierarchy. Adam Smith had already described market forces as the more efficient allocation mechanism for a large number of diverse process participants in his work, "The Wealth of Nations" back in 1776 [Smit76].

On the following pages, "blockchain" moves into the background in favor of the application field of the energy sector. This is due to the fact that this chapter also can be understood as a requirements definition: What will be required in the future in order to coordinate the power grids and the energy markets? Is the "blockchain" suitable for every situation? Or are there requirements which, as before, are better fulfilled "classically"? In this context, we want to remain "blockchain-agnostic" with regards to application processes and also illuminate such processes in which the blockchain makes less sense.

4.1 Energy trading and energy transmission in the past

Traditionally, before the year 2000, there was hardly an energy market, i.e. particularly electricity and gas were produced on the side of the suppliers and consumed by the industry and consumers in one value chain. Demand could be derived from historical key indicators and short-term adjustments to unexpected deviations were made by the generators themselves upon the basis of measurements of frequency and voltage deviations.

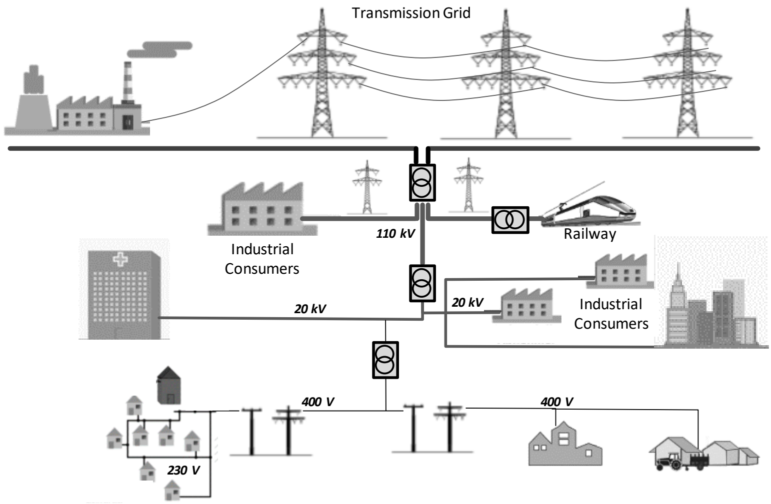

Figure 50: Electricity grid operators, generators and consumers

However, during the course of the liberalization of the European energy market, the players who were participating in the energy market and vertically disintegrated received the opportunity to also procure energy deliveries from other providers.

I.e., consumers became able to seek out their suppliers based upon their unique conditions as well as also suppliers choose the producer of electricity. In order to attain the required transparency, interchangeability and standardization of energy deliveries, the market roles of the participants in the energy sector were more precisely defined.

As the result of the *unbundling*[69] initiated by the lawmakers, a very large number of buyers and sellers meet on today's energy markets who not only exchange a lot of data and engage in an ever-increasing number of transactions, but rather require in this regard a high degree of standardization in the sense of "Yin-Yang-Yong" (See Figure 2). The underlying B2B integration processes are designed in various forms as will become clear later. Some of them are and will remain classically-organized (1:1 communication or through central platforms) while others are better suited to the principle of the blockchain – the "publication of data into the blockchain", based on 1:N communication.

Who are now the essential players on today's energy wholesale market?

- *Generators* supply electricity or gas into the grid. In this regard, generators these days can also be private operators of PV plants, wind farms or biogas producers, but naturally also the traditional operators of nuclear, coal or gas power plants.
- *Trading organizations* (short: Traders) purchase energy in the wholesale market from the generators or other traders and resell it to other traders or suppliers. In this regard, the wholesale market is a European-wide marketplace where some products are resold multiple times until they finally reach the consumer via a supplier. In liquid markets, this "churn rate" reaches a value of 10-15 resells.
- *Suppliers* usually purchase large energy quantities from traders on the wholesale market and offer products which fulfil the special requirements of the industry or the private consumer.
- *Consumers* procure corresponding products from the suppliers. Should consumers supply or store energy in addition to their consuming activities, they act as so-called *prosumers*.
- Electricity and gas are physically delivered via grids which are operated by *transmission and distribution system operators* (TSOs and DSOs). The former are horizontally connected to each other throughout the continent and safeguard the stability of the entire network via various processes – particularly through the balancing of the grid load in order to keep the DC frequency at 50 Hertz.

[69] "Unbundling" means the partitioning of vertically integrated suppliers into specialized companies. In energy trading these are separate organizations as generators, suppliers, grid operators and trading organizations who all were previously much closer tied to the same company group.

One of the main tasks of a TSO is to guarantee the security of supply. DSOs operate distribution grids and the connections to generators and consumers.

- *Meter operators* read the meter data of consumers and generators and forward them to the DSOs.
- *Energy exchanges* operate a marketplace where electricity and gas products can be traded. These marketplaces are regulated, i.e. among others, they are monitored by national regulatory authorities and have a special coordinating role: they are responsible for certain functional processes with system operators such as the submission of schedules, market coupling with other exchanges, etc.
- *Clearinghouses* are linked to one or more exchanges and are responsible for the financial and physical settlement of energy trading transactions. In the case of a default of a market participant, the clearinghouse participates in the market and procures lost energy deliveries and compensates lost payments (this happened, for example, in the European energy markets in 2008 because of the insolvency of Lehman Brothers).
- *Brokers*: Traders are not restricted to trade only via exchanges. In the European energy market, traders can conclude transactions also off-exchange on a large number of broker platforms or OTC platforms (OTC means "over-the-counter"). However, in this case, the broker is merely the intermediary between a bilateral transaction while clearinghouses act as a counter-party to the market participants. Lastly, traders naturally also conclude bilateral transactions directly with each other. Brokers and exchanges serve here as the price signal transmitters.
- An additional role in conjunction with the energy market is the role of the *index agency* (also called PRA – price reporting agency). It determines the current market price for energy products based on trading platforms or by contacting the individual traders and once again provides it back to the traders for a fee.
- *Standardization committees* and *industrial consortia* formalize energy trading processes. Particularly in this regard *EFET* should be mentioned (European Federation of Energy Traders) as well as *ENTSO-E* and *ENTSO-G* – both are associations of electricity and gas TSOs, respectively, which help standardize grid-related processes. Moreover, this list is continued on the national level with

associations such as the BDEW and the VKU in Germany or Österreichs Energie (Austria's Energy) and the VÖEW in Austria.

- Finally, there are *regulatory authorities* which monitor the energy markets on the national or European level. They are technically involved in trading processes particularly due to the reporting obligations for wholesale trading transactions. Directives such as REMIT, EMIR and MiFID-II were initiated over the recent years by the European Commission so that traders have to report data for the various trading transactions to the regulatory authorities.

Numerous products are traded in the energy market between generators, traders and suppliers: Firstly, there are long-term transactions whereby annual, quarterly or monthly base load[70] is traded (*forward market*). On the short-term end, there is the *spot market* which covers the *day ahead*, but also individual hours or quarter-hours of the following 24 hours (*intraday*). Products on the forward market are broken down into those with physical or financial settlement. In the case of the former, the obligation exists to deliver the respective commodity. The latter also include derivative products such as, for example, options or swap transactions which are, as a rule, concluded by market participants in order to hedge against price fluctuations. On the very short-term end (15 minutes and shorter), the possibility still exists to offer *balancing power* which is tendered by the TSOs and offered by specially-suitable providers as required for grid stabilization purposes.

Analyzed from a distance, the electricity and the gas markets do not differ essentially from one another: Both are very liquid sometimes whereby the electricity market outpaces the gas market in the trend towards a more short-term orientation. For simplification purposes, special focus is placed on the electricity market from now on.

Classical B2B processes in the electricity sector

Because a large number of market players perform the aforementioned roles, it is important that business processes are uniformly implemented between them.

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[70] These are energy deliveries with a volume which is unchanging during the course of the day.

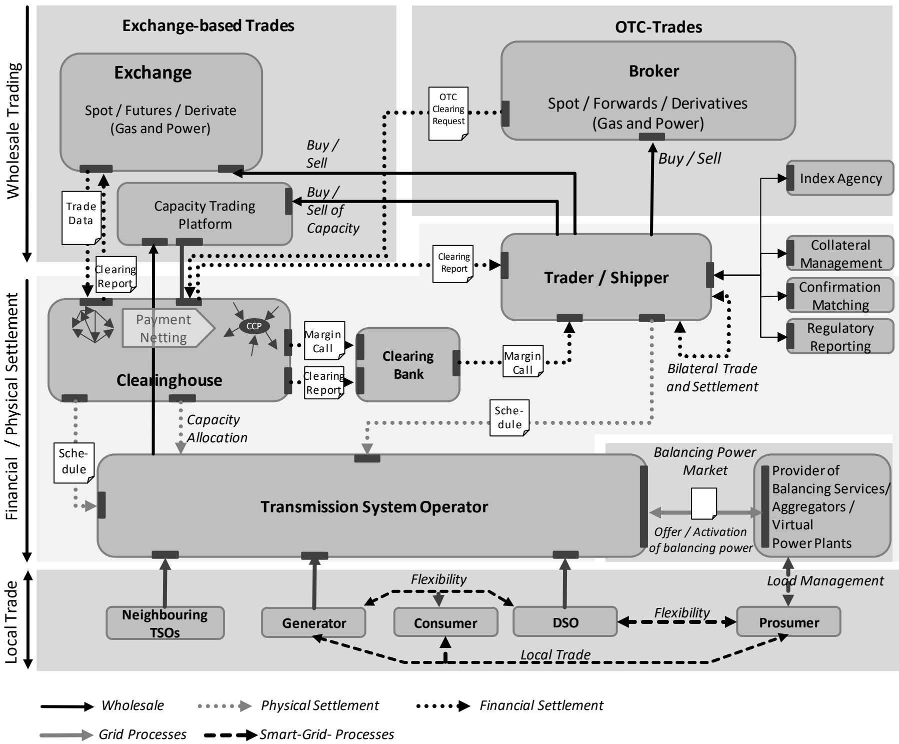

Figure 51: Market participants and processes in the energy sector

Based upon Figure 51, the following processes are performed in connection with a wholesale energy transaction:

- *Trade execution*. This is the process which is the least standardized across the existing platforms because it is individually implemented by the respective platform operators. As a result of the transaction, both parties separately receive trading data via a platform-specific channel. This data is then received into the trading systems of the respective transaction partners (also called *ETRM systems*, for "Energy Trading and Risk Management system").
- *OTC Trade confirmation*: If a transaction has been executed "over the counter" (i.e. off-exchange), both parties bilaterally exchange the

details of the trade in order to ensure that no errors have occurred during the processing in their respective ETRM systems. i.e., there is no single "leading" system by means of which the market participants can synchronize with one another. The reconciliation of the trade data usually takes place upon the basis of the EFET eCM standards (electronic Confirmation Matching).

- *Clearing of exchange-based trades:* This is the processing of trades by the clearinghouse. On the one side, payment settlement is organized for the diverse transaction partners of an exchange. If hundreds of trading participants trade with a large number of other market participants, then payment obligations exist upon the basis of "everybody to everybody else". In order to master the resulting diversity of individual transfers, the clearinghouse breaks down each individual transaction into two halves whereby it itself acts as the neutral, *central counterparty* (CCP). From the S—B transaction between the seller and the buyer, the S—CCP and CCP—B transactions are created. In this regard, the CCP is firstly a buyer and secondly a seller. Topologically speaking, this service of "payment netting" ultimately results in the transformation of a fully-meshed network into a star-shaped payment relationship. Here, the individual amounts of multiple payment obligations are also netted between the CCP and each market participant. An additional task of the clearinghouse is to become a market participant over the short term if a participant defaults which is obliged to make a payment or a delivery. The costs incurred are socialized within the circle of market participants.
- *OTC clearing.* Traders may decide at a later point in time whether to register OTC transactions with a clearinghouse in order to have them processed there. This is customarily done in order to minimize the counterparty risk. Classically, this process is performed via individual interfaces between brokers and clearinghouses whereby the brokers are commissioned by the traders. The service provider Equias offers a standardized process on the basis of the eXRP-protocol[71] which standardizes the interfaces for both sides.
- *Collateral management.* "Collateral" means a security which is provided by a buyer to the seller. Customarily, in case of futures transactions, a portion of the transaction volume is immediately

[71] eXRP – electronic eXchange-Related Processing, see also: http://www.equias.org/.

demanded as security from the buyer (called *initial margin*). If market prices change, a reassessment of the risk situation will be done on a daily basis. If this changes substantially, the seller will issue a margin call from the buyer or reimburse him a portion of the security (called *variation margin*). This process is done bilaterally and is implemented in daily reconciliation processes between the market participants.

- *Nomination* to the TSO. The financial settlement process goes in parallel to the physical delivery of electricity. "Delivery" means that each party who supplies electricity to a power grid or procures it from the grid notifies the TSO in regards to what load and in what time sequence this is supposed to occur. This notification is called a "schedule" and is submitted first at the end of the prior day (e.g., at 6:00 p.m.). During the course of the delivery day, it is updated every 15 minutes. The delivery day itself is broken down into 15-minute intervals so that, for example, on the same day ("intraday"), deliveries still being traded can be included in the following schedules. Traders on the wholesale market must thus be able to submit these schedules in an updated and reliable fashion to the TSO.
  For transactions implemented on an exchange, in some cases, the clearinghouse handles this task, e.g. the ECC (European Commodity Clearing – the CCP of the EEX Group). This way, a market participant avoids the costly process of schedule submission by trading exclusively via the affiliated energy exchanges. On the other hand, clearing costs for forward transactions are relatively high for traders so that a large portion of these transactions still take place OTC despite a general trend towards exchange-based trading.
- *Balance responsible parties (BRPs)*. All producers and consumers who inject electricity to the grid or receive it from the grid need to take care that traded (i.e. planned) volumes exactly correspond to their actual production or consumption. Any expected deviation from the planned volumes needs to be adjusted by executing spot market trades (e.g. intraday hours or quarter hours). Should a BRP deviate from their planned load, the TSO has to adjust the frequency in the grid by activating balancing service providers. After meter data of the BRPs is read and analyzed by the TSO any additional costs from this process will later be passed to those parties whose load had been out of balance plus a penalty fee.

- *Reporting transactions to the regulatory authorities.* In accordance with the REMIT regulation[72], traders are obliged to disclose their orders, trading transactions and additional aspects of transactions to the central agency ACER[73] by the end of the following day. In this regard, ACER has defined in what format, via which reporting platforms and based on which communication protocols the notification must be made. In this context, the most widely used reporting platform is the eRR (electronic Regulatory Reporting) system from Equias[74].
- *Settlement of deliveries.* If traders trade on the exchange, the CCP takes care of the collection and the transfer of payments to and from each market participant. However, the main volume of electricity is traded in the OTC market, i.e. delivery is made based on a bilateral contract. Settlement is done here by bilaterally netting the due amounts and billing during the month following the delivery. Also in this regard, Equias is the main European platform organizing OTC settlement matching based on the eSM standard (electronic Settlement Matching)[75].
- *Activation of balancing energy* by the TSO. If it turns out over the short term, i.e. within a timeframe of 15 minutes or less, that generation and consumption of electricity are diverging within the TSO's balancing zone, then the TSO requests the short-term additional generation of electricity – or also conversely additional consumption (i.e., positive or negative balancing power). Based upon the respective timeframe, differentiation is made between so-called tertiary, secondary and primary balancing services: Tertiary balancing power is requested for a 15 minutes period, to be ramped-up within 15 minutes. Secondary balancing power is requested with 5 minutes lead-time and, in the case of a primary balancing power, within seconds. Here, a deviating load situation is balanced in such a manner that generators are directly controlled in order to maintain a frequency of 50 Hertz. The balancing service is tendered by the TSOs,

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[72] European Union, EUR-Lex - 32014R1348 - EN - EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.363.01.0121.01.ENG

[73] "Agency for the Cooperation of Energy Regulators". Available at: http://www.acer.europa.eu/

[74] eRR Platform for the Regulatory Reporting: http://www.equias.org/

[75] https://www.equias.org/esm-electronic-settlement-matching

only qualified providers are permitted to participate in this procedure[76]. In this regard, the TSO purchases, on the one hand, balancing power from the provider and invoices, and on the other hand, the so-called *Balance Responsible Party* (as a rule, these are also trading organizations) who have supplied or consumed more or less energy in deviation from their scheduled quantities. This way, the TSO itself also becomes a market participant. The determination of this deviation subsequently encompasses, among other things, the respective meter readings of the consumers and generators which have been collected via meter operators.

- In the case of a high generation capacity through renewable energy sources (above all wind energy), the DSO conducts the so-called *curtailment of renewable energy sources* in which generators are throttled-down in order to limit the grid load. In accordance with the German EEG (Renewable Energies Act) renewable energy sources are treated in a prioritized manner vis-à-vis classical generators and are only then curtailed if there are no other alternatives (called "feed-in management"). However, in this case, the general consumer of power must nevertheless pay for the lost electricity production via the EEG levy, which costs 1.4 billion Euro to consumers collectively in 2017[77]. In addition, one expects that the cost for the curtailment of renewable energy sources could continue to increase over the medium term to several billions with the deactivation of German nuclear power plants by 2022 in conjunction with the expanding share of renewable energies.
- In this regard, there exists a strong need for the avoidance of the curtailment of renewable energy sources in Germany by creating *flexibility markets* (also called "smart markets") through which load adjustments on the generator or consumer side can be activated. While the TSOs' balancing process serves to support network stability and generally balances out discrepancies between generation and consumption, flexibility is requested primarily by DSOs in order to mitigate local congestions: If generation in local grid areas is too high in order to be transmitted through transformers or power lines to higher levels, a bottleneck is created which, for example,

[76] Tendering Platform of the German TSOs for Balancing Services: http://www.regelleistung.net

[77] All these regulations are specific to Germany and may be implemented differently in other countries.

can be balanced out through temporarily-increased local consumption.

From the perspective of classical wholesale trading, the overall process has been roughly broken down into the steps shown in Figure 52. The trading (in the *front office*) leads to a trade for a specific product (electricity or gas, spot or forward transaction with physical or financial settlement). The trade data is then received from the trading platform into the ETRM system. The aforementioned processes run on a step-by-step basis. Initially, *back offices* reconcile the trade data with the counterparty. Then the transaction is reported to the regulatory authority. Until delivery is made, a reassessment of the position is made on a regular basis which may result in an additional exchange of collateral and, shortly before delivery is made, schedules are sent to the TSOs which are created by balancing all trades for each balancing group[78]. After delivery, settlement is performed with the counterparty and, in case of a deviation of the actual production and consumption from the reported plan, the TSOs will bill the Balancing Responsible Party for the required balancing energy.

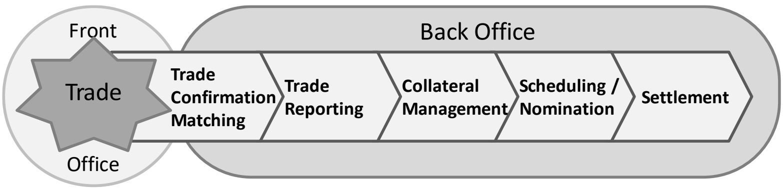

Figure 52: Process sequence during the wholesale trading of energy

One can continue this list of processes as long as desired if one shifts the focus from trading to grid operation. However, the aforementioned processes already suffice as a universal set in order to later be examined for blockchain compatibility. Perhaps you would already like to ponder what processes are actually blockchain-compatible and with which the blockchain would make no sense? Every person naturally has his own assessment criterion in this regard, but perhaps it will be more interesting in the following

[78] Within a balancing group (e.g. the one of an electricity generator or a large consumer), it must be ensured that the generated or consumed quantities correspond at all times to those sold or procured on the market.

pages to check the individual pro or con blockchain hypothesis against the subsequent details?

4.2 Current and future developments in the energy market

What direction is the electricity market moving today and in the future? Why is "blockchain" currently so much discussed with regards to the electricity market?

Throughout the years during the energy transition in Germany, some parameters in electricity trading have drastically changed: Initially, the share of renewable energies increased dramatically whereby Germany became the global laboratory for renewable energies. For example, on New Year's Day in 2018, Germany supplied itself with 100 % electricity from renewable energy sources for the first time – this has not yet been reached in any other region[79].

Such situations have occurred quite often in recent years: For example, an earlier world record was attained with a coverage of 95 % of the German electricity consumption through renewable energies on Sunday, May 8, 2016. On that day, it was claimed to have been the best "sailing weather" with perfect blue skies and a great wind. Moreover, due to the fact that it was also an extended weekend, the industrial consumption was respectively low so that the consumption load of 53 GW was 12 GW lower than during a weekday. But, furthermore, the following was noteworthy for that day: There was a dramatic generation surplus. Power was thus traded a "day ahead" at *minus* 12.89 Euro per MWh. i.e., buyers were rewarded if they bought electricity. The lowest price for the peak load was *minus* 36.46 Euro per MWh on this day and an hourly contract was traded at an astonishing price of *minus* 135 Euro per MWh! More and more frequently, electricity is available in the wholesale trade at minimal prices. This has to do with, among other things, the fact that the "classical" generation on the basis of nuclear power and coal is not able to correspondingly reduce the generation load within only a few hours and is forced to find a buyer – regardless of the cost. On May 8th, 13

[79] http://www.sueddeutsche.de/wirtschaft/oekostrom-an-neujahr-versorgte-sich-deutschland-erstmals-nur-mit-oekostrom-1.3813875

GW was generated as a surplus which streamed at negative prices to neighboring countries.

Generation is obviously not as plannable as in earlier days. There are already days when the weather has changed so drastically from the previous day's forecast that a discrepancy of more than 5 GW occurred in Germany. This is equal to the output of 5 nuclear power plants and corresponds to almost 8 % of the total consumption. As a result of this volatility which cannot be completely forecasted, situations arise today in which balancing energy takes on a growing share of the generation. However, this process was originally not planned at all with regards to volumes. In this regard, we have already identified the following trends in the electricity market today:

- *Shift from the forward market to the spot market* and further to balancing energy: Why should a trader cover himself with energy over the long term on the forward market which costs 40 or 50 Euro per MWh when it is available in the short-term (particularly intraday) on a free-of-charge basis or even cheaper? However, on the other hand, there can be nights or foggy days with no wind. Conversely, one can protect himself only by correspondingly securing his supply over the long term. But the tendency is that, due to the very low marginal costs for PV and wind, on average, prices will go down due to the high percentage of renewable energy so that traders on the spot market will be able to very cheaply cover an increasing share of their requirements in the short term. Consequentially, the volume of the German intraday spot market has more than doubled over the last four years.
- *Decreasing generation costs*: In May 2016, a provider in Dubai won a tendering procedure for the operation of an 800 MW PV plant which guarantees the supplying of electricity for 2.99 USD cent / kWh.[80] And even in the case of the tendering procedures for German wind farms hardly any subsidies have been required since 2017.[81] Renewables with low marginal costs have thus increasingly supplanted old energy sources (coal and nuclear power) on the

[80] http://www.pv-magazine.com/news/details/beitrag/third-phase-of-dubais-dewa-solar-project-attracts-record-low-bid-of-us-299-cents-kwh_100024383

[81] Initially, in April 2017, the construction of an offshore wind farm was offered by EnBW for which no more subsidies were requested: https://www.welt.de/wirtschaft/article163681001/Die-brutale-Kostenwahrheit-ueber-die-Windkraft-Branche.html

wholesale market. At the same time, so-called *aggregators* and *virtual power plants* couple and bundle hundreds to thousands of small generators and offer them as a balancing service or on the spot market.

- *Reduced transaction volumes*: Finally, the transaction volumes have been reduced with the shift to spot and balancing energy. If 10-100 MW had previously been traded for a period of months, quarters or years in wholesale trading, these days, the percentage of smaller 15-minute contracts has increased on the spot market of the EPEX Spot. Among other reasons, this is also attributable to the need to balance out short-term volatility in generation. Today, the minimum tradeable quantity is a 15-minute contract for the delivery of 0.1 MW of electricity.

Figure 53: Decreasing power prices on the German futures market

Figure 53 (source: ICIS [Kott16]) shows the development of electricity prices between 2009 and 2016. With the increasing proximity of the delivery period (X axis), prices decrease for the annual base load contract for a respective year. In addition, in the case of the same time distance to the delivery period, the prices also decrease which must be paid on a year-on-year basis. Overall, the electricity prices in wholesale trading decreased from more than 60 Euro to sometimes less than 30 Euro per MWh. However, there has been an upward trend again since 2016, although prices are expected to decrease in the long-term.

In the future, we will see quantities being traded at a reduced price with decreasing volumes and being traded over a shorter term. If, in this regard, transaction costs do not simultaneously decrease, then trading will become an unprofitable business – and this is precisely the case today for many market participants. Some trading companies have already become unprofitable and many are threatened to become unprofitable because diverse cost factors are not fundamentally changing:

- *Internal costs of trading* will remain high as long as the "human" factor is involved. Traders themselves are highly-paid, but also neighboring departments such as legal, IT as well as the overall set-up of a front office (trading), middle office (risk management) and back office (processing and settlement).
- The *external costs* remain high: Clearing and exchange fees, broker fees, trading licenses, index agencies and additional service providers generate costs which can be respectively very high for a spot transaction.

Some examples are highlighted below which show what types of transaction volumes and amounts we are working with in the respective markets today:

Table 5: Comparison of electricity products and their prices

Market	Product	Volume	Total Amount
Forward	Annual base load contract, 10 MW, 30 Euro / MWh, 8,760 hours	87,600.000 MWh	2,628,000.00 Euro
Forward	Monthly base load contract 10 MW, 30 Euro / MWh, 720 hours (for 30 days)	7,200.000 MWh	216,000.00 Euro
Spot	Day-ahead, 1 MW, 30 Euro / MWh	24.000 MWh	720.00 Euro
Spot	Intraday, 1 hour, 30 Euro / MWh	1.000 MWh	30.00 Euro
Tertiary Balancing	1 MW, 15 min., 50 Euro / MWh	0.250 MWh	12.50 Euro
Primary balancing Service	Battery storage device, 200 KW, 5 min., 100 Euro / MWh	0.017 MWh	1.70 Euro
Spot	Intraday-tradable on the EPEX Spot, 0.1 MW 15 minutes, 24 Euro / MWh	0.025 MWh	0.60 Euro

The examples on the bottom end of Table 5 show that the volumes of intraday-trades frequently correspond to micro-transactions with prices under 10 Euro and that at some point one must transition from the human-based (futures and day-ahead) to automated trading processes.

Managing congestions

Besides the aforementioned trends, there is also an additional factor: Up until now, we have discussed the transactions and prices on the wholesale market. In this regard, the TSO, with its balancing zone, represents the area for wholesale electricity deliveries. However, renewable energies are regionally produced whose generation load cannot always be distributed in any arbitrary way. e.g., if there is excess generation in distribution grid area 1 and excess demand in distribution grid area 2 and no direct connection exists between them. This can result in congestion situations on the superordinated grid levels which connect areas 1 and 2.

In the future, a DSO should pursue the goal of covering as much local consumption as possible through local generation – or vice-versa, depending on the situation. It must act like a TSO upon a small-scale basis, i.e. create mechanisms which it can balance between generation and consumption. One can summarize this in shortened form as *smart grid processes*. The goal here is that interventions are being made into the planned load behavior on both the generator side (PV, wind, biogas) as well as also on the consumer side (industry, office buildings, hotels, private households), in order to balance out fluctuations on the supply or demand side (also known as *supply side management* and *demand side management*). In this context, one also speaks of offering or requesting *flexibility*. Generation units and consumers are "remote-controlled" in order to relax congestions within a grid area.

As a rule, small generators and small consumers do not directly participate in wholesale trading. They are situated inside a distribution grid which has its own requirements regarding load management and which may activate flexibility. In parallel, aggregators serve as intermediaries linking these small participants to the balancing market or to the spot market. In this regard, the small participants should be able to decide in what regime they wish to be integrated.

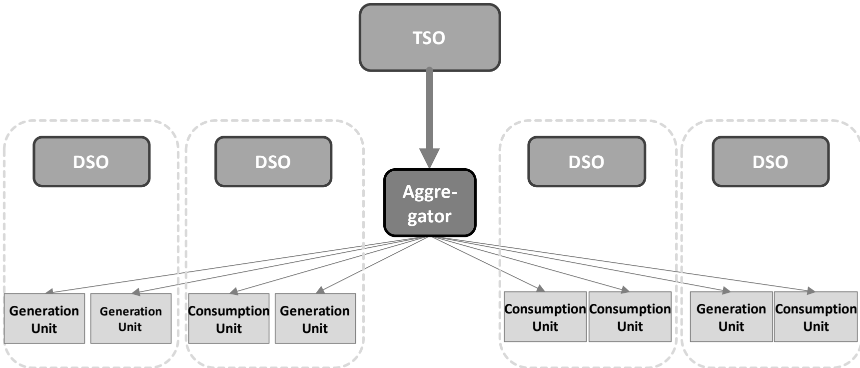

Figure 54: Interplay of TSO, DSOs, aggregators and local producers / consumers

Today however, it is difficult for generators to switch the aggregator, i.e. to freely decide who is supposed to be their transaction partner within the grid. The rules and protocols for the data connection of a generator are sometimes still aggregator-specific. If a liberalized local market is established in the future – as in wholesale trading today – then also the small participants are free to offer their energy to any aggregator or direct transaction partner with whom they will reach agreement on an individual price.

Trading low-cost quantities requires an infrastructure with costs that need to be dramatically lower for small-scale transactions. Only then, flexibility can be offered or requested: If charging a 10 kW battery for 15 minutes at 30 Euro / MWh has a transaction value of only 7.5 cents, then the transaction costs should lie below one cent. Whether this is efficiently implementable with today's infrastructure is questionable. In addition to the technical progress, it depends on the regulatory simplification of the processes above all.

If we shift the focus from the TSO in 2020 to the DSO in 2030 we will assume the following scenario:

- that the installed generation capacity in Germany on the basis of renewable energies lies around 230 GW (compared to 120 GW in 2019) which would be more than three times the peak consumption,

- that a portion of the surplus production can be placed into intermediate storage during peak times (e.g. not only with affordable battery storage systems but also hydrogen-based storage by then, as seen in the Prologue) and supplied as comparatively cheap energy,
- that the spot market will become the main hub of wholesale trading and, at the same time, the cut-off time for trading short-term energy approximates cautiously up to a few minutes before the delivery interval,
- that, by the trading of flexibility on local and regional markets, micro-transactions in the amount of a few cents will become commonplace,

then we can envision that our current IT systems and energy management processes will no longer be able to meet such requirements. Ever-increasing real-time requirements, the necessity of maintaining and updating software systems during on-going operations, a de-facto 100 % availability rate, the simultaneous necessity of further automation and cost reduction in addition to fulfilling the most important goal, security of supply, altogether requires a complete rethinking of the planning of IT infrastructures for the trading and the delivery of energy.

If individual prosumers and consumers are still also supposed to offer flexibility, then standardized processes are required, because each small generator would have to assume an unreasonable additional switching costs if transaction partners would not be interoperable with regards to those standardized processes. Any adaptation-related expenditures to regional particularities would not only trigger costs for the usage, but rather may put the security of supply at risk.

It can be concluded that gigantic data quantities are moved individually back and forth these days between gigantic “data silos” in energy trading and the related processes. Many data exchange relationships between market participants are still so strongly-individualized that the ideal of the initially-mentioned Yin-Yang-Yong can at best only be partially implemented in accordance with pan-European standardization. If micro-quantities of electricity are to be traded, delivered and also still paid for at micro-prices in real-time while guaranteeing security of supply, can the blockchain play a role then in the future?

4.3 Usage of the blockchain in energy trading

In this sub-chapter, we want to now analyze what the blockchain can contribute to energy trading. It is probably a question of imagination to predict what course this development will take, but one can also very well envision that some developments will run their course rather quickly –in the next 1-2 years – and others will require a fundamental transformation of previously-practiced processes which can be expected to take 10-15 years. This also depends very much on the extent to which the regulatory authorities discover the blockchain for themselves and can support or accelerate a standardization that facilitates local trading, local energy communities and a market that spans beyond today's wholesale products.

Potential developments of blockchain-based energy trading are described in the following. Short-term ones are addressed at the beginning of the analysis and the longer-term, more speculative ones at the end:

- The *current approach to the blockchain* in the energy industry still consists of prototypes and "proofs of concept" – even if the marketing divisions want you to believe otherwise. However, some projects are not that far away from production-readiness.
- In the more evolutionary *Scenario 2021*, classical wholesale trading will remain in the foreground. In this case, the usage of blockchain will concentrate on the optimization of some "legacy" processes which seem suitable for the blockchain's technical profile.
- The rather visionary *Scenario 2030* in Chapter 4.4 uses assumptions with regards to price development and regulatory easing to go one big step further: The target will be: "Everything which can be automated will be automated" and "Everything that can be traded will be traded". Consequently, electricity will be traded automatically on all grid levels.

These scenarios remain abstract for the time being. In Chapter 6, concrete project examples will follow.

4.3.1 Status Quo: Blockchain and energy

Initial projects, in which the blockchain is used in order to book energy transactions have started already some years ago: In March 2016, the announcement was made that the world's first energy trade had been made over the blockchain in Brooklyn, New York. In this regard, the owner of a solar roof sold a couple of kilowatt hours to a neighbor, using an Ethereum smart contract. This became visible as the Brooklyn Microgrid[82] which resulted in a worldwide echo as the "Big Bang" of decentralized energy trading. It also inspired further P2P trading projects which want to promote the direct trading between prosumers and consumers in the neighborhood. In Germany alone, around 100 such projects have been initiated since 2016.

The example of the "Brooklyn Microgrid" shows in exemplary fashion how a smart contract can be used in order to trigger a delivery among neighbors, but context-wise this fits more suitably into "Scenario 2030". As a one-time transaction, this is still somewhat of an arbitrary process on planet Mars, not very deeply entrenched in the world of DSOs, TSOs, energy suppliers and meter reading services on planet Earth. It should be considered instead as a marketing event – representative for many such projects which promote the usage of blockchain in energy trading.

Another early project came from Germany: Innogy was striving, in cooperation with their partners from the energy and automotive industries, to set a standard for the charging infrastructure on the basis of blockchain technology in order to use a payment process in the electric vehicle segment to make charging transactions billable at public charging stations for electric vehicles. A billing unit is used here which supports the various operators of charging stations to enable drivers of electric vehicles to make a standardized payment. Innogy's system was initially based upon an Ethereum smart contract. However, with the rolling-out thereafter, a higher-performing technology for the B2B integration was required for a possible mass distribution whereby, above all, it must be cheaper with regards to the transaction costs. However, the project "Share & Charge"[83] has been abandoned in early 2018

[82] www.brooklynmicrogrid.com
[83] www.shareandcharge.com

and restarted later in that year as a foundation. The underlying blockchain technology is based on the Energy Web Blockchain.[84]

The TSO TenneT and the home battery vendor Sonnen and, indirectly, the owners of PV units are cooperating with the goal of unlocking flexibility to relax the German transmission grid of TenneT. This is done in congestion situations through the controlling of the battery storage devices in the north and the south of Germany. If a congestion occurs on the north-south transmission line of the power grid (high wind production in the north – high industrial consumption in the south), then the batteries in the north are requested to absorb the electricity and those in the south are requested to discharge it. In a way, the effect is a virtual "tunneling" of the delivery via the batteries of the respective regions. However, this is also a project in its infancy state, as the blockchain, based on Hyperledger Fabric, only connects two participants – Sonnen and TenneT. Any remote control between Sonnen and their batteries is based on classical 1:1 telecontrol links. Regarding the TenneT-Sonnen link, one may also think of alternatives here, e.g., to use SFTP as a data communication protocol for such 1:1 communication – that hard part still needs to be tackled. Also, the total flexibility potential of 1 MW is still a minor volume based on 600 batteries, each owned by an individual household.

Another project that gained some visibility is Enerchain – of which I am quite personally proud because it is my personal "brainchild". Enerchain is a decentralized marketplace for decentralized energy wholesale trading using blockchain. Find more on this project in Chapter 6.1.

4.3.2 Scenario 2021: Evolutionary application of the blockchain

Over the near term, one can envision that the current, deep-rooted processes for energy trading will tend to be supported by the blockchain (evolutionary approach) rather than outright supplanted by it (revolutionary approach). The overall structure of the market in Figure 51 will initially not change, but the "silo building" and the individual data exchange could be supplanted by the blockchain or at least improved through data synchronization.

[84] energyweb.org/blockchain

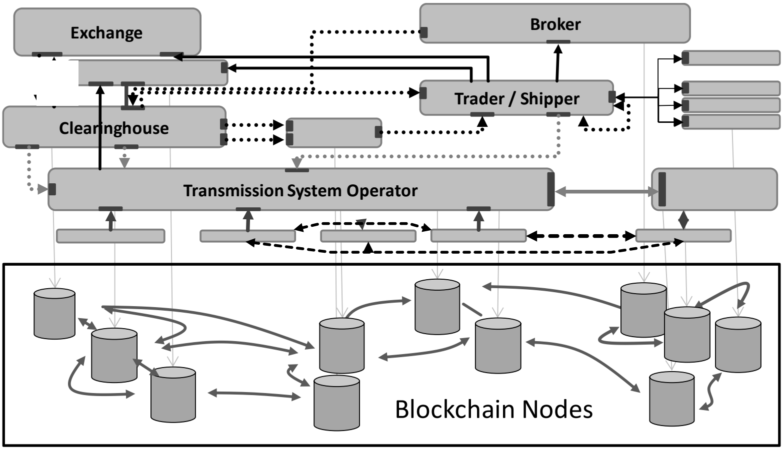

Figure 55: Blockchain supporting traditional energy trading processes

A first step can be the usage of the blockchain as a communication channel. Here, all market roles remain intact, traders trade with traders, brokers and exchanges are available as platforms and TSOs receive schedule data.

Essential players in the system may operate a node. This can be traders, platform operators, grid operators, IT service providers or other third parties. In any case, this will be a permissioned blockchain whose communication between nodes on the one side (for data synchronization, horizontally on Figure 55) and between participants and nodes on the other side (vertically) is secured.

The most important effect initially is the standardization. If only one blockchain environment should exist on the entire continent, all participants would have to send or receive the data in the exact same format – a perfect implementation of the Yin-Yang-Yong. Previously, P2P processes took place on an individual application level. I.e., in the blockchain era, functional processes no longer "speak" directly with each other, but rather via a *client adapter* which maps the functional processes and data to the blockchain. On the blockchain-facing layer, the adapter supports a technical interface and, on the application-facing side, a functional one. Transactions are thus used as a container and the blockchain as a transport vehicle in order to disseminate data – quite in the sense of the profile of B2B integration following the 1:N communication pattern.

If a trade is done, e.g. via the Enerchain infrastructure, then its data is visible for everyone accessing the blockchain. This "golden copy" forms the starting point for numerous downstream processes which no longer have to be synchronized bilaterally between individual market participants, but rather only vis-à-vis the immutable "data truth" in the blockchain. This spares the synchronization between the market participants' silos. Instead synchronization is reduced to the market participant and the blockchain.

Scheduling process

Accordingly, one can envision that a trader who sends a schedule to a TSO will write this into the blockchain and the TSO, which itself operates a node, will directly read out this data. Its adapter delivers just the data which is relevant to it, i.e., schedules for its balancing zone.

OTC Clearing Process

Similarly, one can envision that a broker will also send transaction data to a clearinghouse under the aforementioned OTC clearing process.

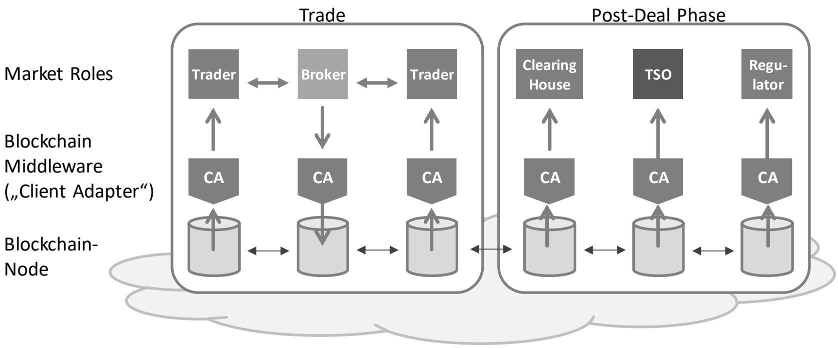

Figure 56: Evolutionary utilization of the blockchain

Via the left half of Figure 56, "only" the standardization of the trading-related data communication and the filing of the golden copy is achieved. The right half adds additional processes by connecting additional data recipients to the blockchain without this constituting a significant expenditure for the market participants.

Price reporting by index agencies

Initially, it was mentioned that index agencies have specialized in determining market prices for specific traded products and reselling them to the traders. Most notable in this regard are services like Bloomberg and Thomson-Reuters as more generally-known representatives and others like Platts, Heren and Argus as specialists in energy trading. While prices for liquid products such as the electricity base load for the year ahead are published by many exchanges and brokers, these index agencies also specialize in less liquid ones such as, e.g., Belgian base load. To calculate price forecasts, they query traders at certain times of the day – sometimes by telephone – and ask at what prices products have been traded. Via averaging and smoothing functions, a daily or a weekly index value is created which sometimes has only minimally reliable sampling points. This is published and made available to the traders and marketplaces in order to trade derivatives using this as an underlying index.

Whichever data is stored in the blockchain can be used by diverse parties as the data source for subsequent transformation steps. In this regard, each trading organization itself is enabled, based upon a standard formula, to determine the index for certain products from the database shared by all participants. Index agencies have the reputation of being quite costly for traders because they take the data, which they just retrieved from the traders, and then sell them back to them a moment later. In the blockchain world, it is clear that price index information, which has been published into the blockchain, will be transparent to other market participants: Blockchain transparency and immutability can be ideally used.

Regulatory transaction reporting

The regulatory authority can be integrated as a blockchain user as well. It would merely access a node and receive transaction data nearly in real-time, compared with the current delay. This requires no additional costs for the market participants who have a reporting obligation. And an ambitious regulatory authority who tracks transactions with real-time surveillance software in order to monitor the market can now actually participate in real-time and not by using a "replay" function on the following day. If everyone (traders, exchanges and brokers) who must report transaction data writes into the blockchain, then there is nothing further to do than connect the regulatory authority to the blockchain.

With regards to this evolutionary approach, what are the specific requirements for the blockchain now?

Table 6: Requirements for the blockchain in the evolutionary scenario

Blockchain aspect	**Requirement**
Availability	A failed blockchain node should be functional again within a minute and a connection to a fallback node should be established within seconds. A consortium blockchain should consequently run with 7 or 10 nodes in order to approach 100% availability (based on a PoA consensus mechanism).
Immutability	For some trading-related processes, it is beneficial if trade data is written into the blockchain in immutable form. Subsequent post-trade processes are then based on this data. However, as this data is also kept in various application systems, it would be beneficial if the history for this data could be pruned in the long term.
Throughput rate	In the case of peak loads, the system should be able to reach several hundred transactions per second. High-load scenarios with more than 1,000 transactions will probably not be solved by one global blockchain. A hierarchy based on regional blockchains would be necessary.
Block time	Due to the evolutionary character, it suffices for most processes if the block time is approx. 5-10 seconds because today current processes are substantially slower. Merely in the case of the trade execution, a block time of one second is beneficial in order to approach the real-time character of the trading process.
Trustlessness	If only a portion of the market participants operate nodes, then it must be ensured that these market participants have no opportunity to view the data and thus have insight in their competitors' commercial secrets.
Data Volume	If one uses the current data volume of the REMIT reporting as an estimation basis, then the monthly data volume may lie in the dimensions of terabytes.

Blockchain aspect	Requirement
Smart Contracts	These are not the best choice for the B2B integration (if in Ethereum style) due to the data volume and the standardization of the processes. Smart Contracts also do not allow a secure execution, as node operators may exploit the possibility to read out the main memory of a node. Additionally, an efficiently-organized updating of the software logic is required.
Consensus mechanism	PoW would not make sense due to the high energy consumption and vague finality. PoA across a selection of node operators would be appropriate.
Transparency	Important: Certain transaction data may be available only to authorized users. The possibility for end-to-end encryption is required by the participants.
Anonymity / Pseudonymity	Because traders compete with each other, reciprocal data protection is key. Some processes require anonymization of participants (e.g., the submission of orders on a marketplace) while others require their identification. On the other hand, selected participants (TSOs, regulatory authorities) must be able to identify participants in any case. In this regard, the aforementioned anonymization only applies to a part of the blockchain users.
Token currency / payment	In the case of trading transactions, it would be sensible to perform instantaneous payments as trading transactions are executed.

There does not always have to be a blockchain…

In addition to all the euphoria surrounding the "blockchainification" of the energy world, one should keep in mind that there are also processes whereby the blockchain is not required, e.g. because data is exchanged only bilaterally, i.e. whereby third parties are not supposed to have access to them. If, however, the principle of "publishing into the blockchain" leads ad absurdum, one should then better examine whether a central platform or a solution with 1:1 communication is more beneficial.

4.3.3 Applying blockchain to post-deal processes in energy trading

This section focuses on existing processes and how they can be optimized in the light of blockchain-based B2B integration. However, this applies only to some processes while others continue to be better implemented in a centralized form as this is the more efficient variant for them.

OTC settlement

This is the bilateral billing of electricity deliveries. Trader A invoices Trader B for a list of deliveries and Trader B expects that Trader A will include these positions on the invoice because Trader B, as a counterparty for each of these transactions, will know precisely what amounts are to be paid. Ideally, the data of both parties should match exactly. In the case that is not so ideal, the parties must use lengthy, manual processes in order to try to root out the errors and discrepancies which make this process of invoicing preparation extremely inefficient.

In this regard, how can the blockchain now help? Certainly not as a data exchange channel because this works much easier through 1:1 communication via one of the B2B integration protocols like AS2, AS4, or ebXML. However, could a smart contract keep the invoicing positions in synch? In order to do this, they would have to be supplied by both parties to the smart contract in order to be reconciled by it. In this regard, the positions from Party A would be received first and then intermediately stored in the smart contract until the ones from Party B are received. Then the smart contract does its work. But stop! Intermediate storage? That can be done only in encrypted form. However, an Ethereum smart contract stores data in unencrypted form in the blockchain. Even if channel encryption was realized, the data would still be located in unencrypted form in the main memory – and this would once again be open to interested parties like a barn door thanks to the usual hardware bugs (See Chapter 3.4). Consequentially, even so-called "secure smart contracts" won't help here. If the node is hosted by a third party (e.g. another market participant), then this third party could also spy on his competitors.

If, however, as the result of energy trading, the trade data is already available as the "golden copy" on the blockchain and the settlement data can thus be derived therefrom so that each market participant is synchronized with this golden copy, then they are by definition also automatically synchronized with each counterparty, i.e. they require no additional process for this (in this regard, it is likewise unimportant whether this is encapsulated in a smart contract or conventionally implemented).

For the reciprocal billing, essentially a 1:1 process is more beneficially implemented using a 1:1 communication infrastructure than a 1:N communication (blockchain). The latter would artificially graft an additional level of bilateralization which makes "blockchain" obsolete. However, if the parties can each reconcile their data vis-à-vis the blockchain they do not need to do this bilaterally anymore. *For this*, the blockchain once again makes sense as the "bearer" of the collective truth. As one can see, these are very fine details which constitute the red line between "blockchain" or "non-blockchain".

Confirmation matching process

This works similarly with confirmation matching: Previously, trade confirmations were exchanged 1:1 between traders whereby the logic was placed locally with each trader for reconciliation purposes – encapsulated in a software called EFET Box. This data is also not at all the concern of a third party as it includes all trade details. Likewise, via the blockchain, trade confirmations would have to be tunneled via a 1:1 channel between both contractual parties. If, however, not even a portion of the data is supposed to be disseminated to the public – why then use the blockchain at all?

Actually, in view of the constantly-increasing number of participants, it was even more efficient to centralize the process because the central operator is considered trustworthy in this regard – so here we don't also find a blockchain case.

Figure 57 shows the natural way and the blockchain-based way for 1:1 communication. Based on the graphic to the left, data is sent simply by means of a classical B2B protocol over the Internet (e.g. AS1, AS2, AS4, or ebXML) while, on the right, 1:N communication is being applied over the blockchain. Here, the sender encrypts the data for the one intended recipient. Node operators and other participants can definitively see the data in encrypted form, but it is of no benefit to them. Consequently, one may completely waive the usage of the blockchain as only the sender and the receiver can access the data.

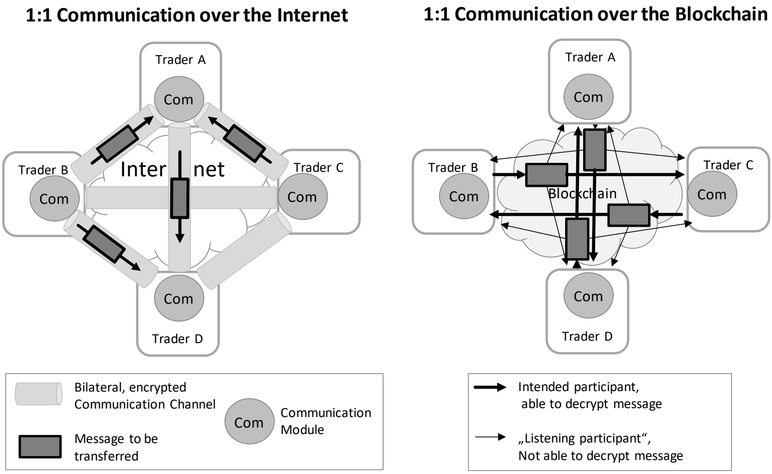

Figure 57: 1:1 communication over the Internet or over the blockchain?

Disruptive effect on the physical settlement of energy trades

The evolutionary scenario still assumes that data and process relationships between the participants are unchanged. However, if one analyzes the illustrated energy trading processes from a blockchain perspective, then, based upon the elevator trip from Figure 1, it makes much more sense to think "bottom-up" and use the inherent characteristics of the blockchain in order to generate added value on the business level. As in many other industries, this added value can not only be quantitative (e.g. through the acceleration of processes), but rather also qualitative by scrutinizing the role of individual participants. In the following, I describe some potentially disruptive process re-designs – but let's first start with a moderate variant:

Scheduling process 2.0?

The fact that all users of the blockchain receive all data makes a process like scheduling in the blockchain era seem somewhat outdated. How does this exactly function today? A Balance Responsible Party accesses the portfolio database with energy transactions every 15 minutes and then filters this based on the delivery period and the TSOs' balancing zones. Therefore, the BRPs retrieves all transactions whose delivery refers to the day for which a schedule is to be created. From these transactions, one determines a time series which corresponds to the net delivery to a balancing zone by netting the delivery quantities based on 15-minute intervals. The BRP transmits this schedule to the TSO which, in turn, verifies whether all other BRPs from their perspective have sent matching data. If this is the case, the TSO confirms the accuracy to the BRPs. Every 15 minutes, this process is repeated. Generation or consumption forecasts are also sent in this format beforehand.

From a blockchain perspective, the process can be simplified in this regard: Why is the BRP supposed to repeatedly make such a large effort to select, balance and exchange data every 15 minutes? Is there another way? A way which is more "blockchain-friendly"?

To find a solution, we only need to look towards Great Britain. The British electricity network operator Elexon has developed the following process: As soon as two traders have carried out a transaction, one of the two (the so-called *ECVN Agent*, Energy Contract Volume Notification Agent) reports the key data from the transaction to an agency of the TSO (the *ECVAA* – Energy Contract Volume Aggregation Agent). The same applies to all modifications or cancellations of trades. This reporting begins with forward transactions years before delivery and ends with spot transactions only 15 minutes before delivery. In this manner, the ECVAA has all information available to it regarding the expected load on the generation and consumption sides, at the earliest-possible point in time. Through each reported transaction, this profile changes and is made more precise based upon the new delivery quantity. The TSO unilaterally conducts the netting and can itself thus determine the delivery quantities of the market participants for each day, broken down by 15-minute intervals.

If traders now store their trade data in the blockchain and the TSO likewise "eavesdrops" on the blockchain, then the nomination process has hereby already been completed the British way! The blockchain would help here to simplify a process which today is burdened down by high expenditures for handling and the costs for the IT budgets of diverse traders and TSOs.

In reality, the ECVNA-based way of scheduling does not work perfectly today because some transaction reports get lost. However, this is due to the 1:1-characteristics of reporting. If trades are executed on the blockchain, their resulting data will stay there. And as the TSOs have access to the transactions, they may also access historic data that they may have missed due to a connection issue. The immutability feature of the blockchain helps here to again synchronize the data state between market participants and the TSOs.

Disruptive effect of the financial processing

Many blockchain projects in the Fintech segment are dealing with the impact of blockchain technology on clearinghouses. There are nowadays various clearinghouses which analyze the technology in order to better understand how their role might be threatened.

In this regard, it is worthwhile to read the joint paper of the consulting firm Oliver Wyman and Euroclear [Euro16]. By introducing dedicated blockchains for the asset side (in this case: delivery obligation for electricity) and for the payment (in a fiat currency or a token-based settlement currency), diverse service providers can be made obsolete within the complex network in financial trading. In particular, the authors have come to the result that *"no central clearing for real-time cash transactions"* is required. In particular, regarding the role of the CCP for spot transactions, the authors write the following:

> *"In a near real-time asset transaction settled for cash, there is no longer a need to clear the transaction centrally (as both sides have pre-trade transparency that their counterpart will be able to meet the terms of the transaction, and settlement happens almost instantly). However, transactions with a longer lifecycle (such as derivatives) still need the advantages of CCP novation to achieve netting benefits and reduced future counterparty credit risk (replacement risk)" [Euro16, p. 13].*

The clearinghouse's role in energy trading has already been described as well as the influence of the blockchain on the physical processing of transactions. If an exchange, as described above, already writes its transaction data into the blockchain for regulatory reporting reasons, then they are also simultaneously made available to the TSO. This portion of the tasks of the clearinghouse (physical processing) has then already been optimized as described in the previous section.

What affects the financial side of the process – the payment netting? Isn't it the star-shaped billing relationship between the CCP and market participants

– indeed itself the result of an optimization? How can the blockchain also be used in this case?

Because most blockchains can be equipped with a token currency, it is not a difficult step to also integrate this into the processing of trading transactions. Or one could alternatively use the copy of an existing cryptocurrency such as Bitcoin exclusively for the settlement of an energy trade. But is it truly necessary to use a token or a crypto currency with a floating exchange rate? As long as energy trading is denominated in a fiat currency like the Euro, an account system (aka distributed ledger) is thus sufficient for also directly booking a payment transaction – similarly to a Bitcoin payment – between two accounts for a given trading transaction. Market participants must top-up their accounts with some liquidity so that they can subsequently perform their trading transactions.

If a spot energy delivery is immediately settled and this settlement costs at most a cent, then the advantage of the payment netting has once again been turned around: For a trader, the usage of the blockchain and thus the distributed ledger is less costly and more reliable due to the immediate booking ("instantaneous settlement") – the payment is just a side effect of the trade itself.

However, there is also a big disadvantage in this solution: The on-chain transaction cash of each trader must be sufficient for unexpectedly large transactions whereby the worst case defines the required liquidity. If in the case of such a transaction, Euros from the classical banking world must be transferred initially to the transaction account, the delivery period for the energy has possibly already lapsed – it simply takes too long. However, it is just as inefficient to constantly have to park an excessively high amount in the blockchain's credit account because this liquidity would no longer be available for other transactions of the company – the trader could use the money much more beneficially for other purposes.

At this juncture, it turns out that the service rendered by a bank for on-chain trade financing will once again come into play again (incidentally, the clearinghouse is itself a bank). Today, traders deposit securities in a clearinghouse in order to reciprocally protect each other against insolvencies of other market participants. In the scenario of the P2P settlement, they would utilize a credit line from a bank which likewise is collateralized through assets.

However, there would still be no processing fees to be charged by the bank for each individual trading transaction, but rather for the supplying of liquidity. Due to its role as a provider of a settlement token, I would call the new role a *coin providing authority*. Moreover, this transaction would be a business model for quite normal banks, i.e. a specialization for the business process of clearing would possibly no longer be required.

Accordingly, the image of the participating market roles appears to be somewhat more disruptive: In addition to the traders and marketplaces, TSOs and regulatory authorities still remain as natural monopolies which cannot be optimized away de facto or de jure.

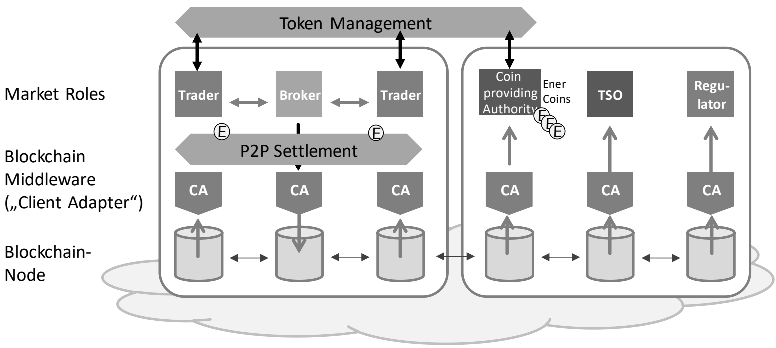

Figure 58: From the clearinghouse to the financier

Disruptive effect on the trading: P2P trading without brokers

One could ultimately argue that a P2P marketplace will never be able to reach the speed and transaction rate of a centralized broker system. This is correct because, for example, transaction rates of only a few micro-seconds are realized in high-frequency trading. But is this then truly required for the energy market? As long as one second suffices to place an order which is to be displayed on a trader’s screen and the transaction is confirmed by a mere click, we will still be on solid ground for the blockchain-based trade execution, assuming the block time can be shortened down to this one second.

If one compares the liquidity of the energy market with the high-frequency trading for other asset classes such as equity, interest rates, financial exchange and their corresponding derivatives, then we will assess that the transaction rate is not in the range of thousands of transactions *per second*. On a more liquid market for electricity forward products we will be closer to 500 to 1,000 transactions *per day*. If one trade is executed each second, then these 1,000 trades are all done after 20 minutes and the platform operator can once again "go to sleep" for the rest of the day. Even for a more liquid spot product like, for example, "15 minutes interval from 6:00 p.m. to 6:15 p.m. with delivery into the balancing zone "50Hertz", there may perhaps occur only between ten to one hundred trades per second – as a rule, within the timeframe of a few minutes in advance of the delivery interval. Obviously, this is also quite a "relaxed" event. But then there are still the truly illiquid products such as, for example, a base load contract for gas with a delivery three years into the future on the Belgian market. Here, we may find possibly at most 10 transactions *per day*.

If the rare order for such a product pops up on the traders' screen, they need a few seconds to comprehend that something has happened. And before they hit the "buy" or "sell" button, several seconds will have passed. The blockchain latency of a few seconds doesn't have any negative effect whatsoever in this case. Please refer to Chapter 6.1 on the Enerchain project which has implemented decentralized P2P trading exactly as described above.

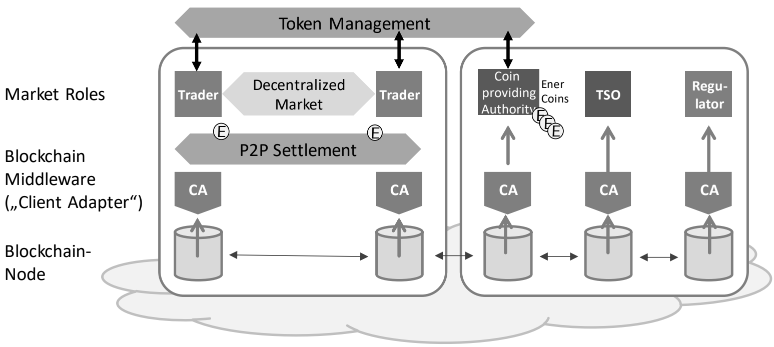

Figure 59: OTC energy trading without brokers

4.4 Scenario 2030: A perfect energy market?

If we place our focus on 2030, what would then be the maximum level of optimization which we could envision? As will immediately be shown, we will, again, focus only peripherally on the blockchain technology for two reasons: First, because the term "blockchain" will probably no longer be used in 2030 – similarly to how we today no longer use terms such as, "datagram" for example, because we no longer perceive the Internet as a "data exchange network" today – and secondly because the scenario is essentially a requirements analysis from which it can later be derived how the blockchain should be designed for future energy markets. The scenario 2030 serves as a prerequisite for the analysis of Chapter 6 as the project examples presented in that Chapter are based on this consideration.

Scenario 2030 is admittedly quite visionary, but what makes it easy for me is that no one can provide evidence to the contrary for a foreseeable timeframe. At this juncture, let's allow some creative ideas to have free rein – so please do not take offense regarding prices and other quantization which could certainly materialize slightly differently in reality than described herein.

In the past, the assumption has been made that the distribution of electricity will take place like on a copperplate – without any capacity limitations. All electrons can flow from each location of the plate to each other location as they are generated and consumed. In this regard, trading anticipates only the delivery from production to consumption based on a portfolio.

Today, the generation output fluctuates greatly, e.g. through a high solar-based generation in the southern German distribution grids or due to a likewise volatile, high share of wind-based generation in the north. In addition to the production forecasted by traders, a non-forecasted share of the production needs to be taken into consideration as well. Overall, these fluctuations push today's grids beyond their capacity limits.

Historically, with regards to private or even typical industrial consumers, so-called standard load curves were assumed which modelled an average household and forecast corresponding capacity reserves for statistical outliers in consumption. Historically, the supplying of electricity to regions was plannable – the generation took place in the high- to highest-voltage grid layers, and, the consumption in the levels below. Historically, trading simply anticipated only the delivery volume which led to the physical flow between power plants and consumers – which required no substantial adaptation of participants and networks.

What is different today – and will be even more different in the future – than in the old days of unilateral supplying? Why in Germany do we pay 10-12 cents more per kWh today than in our neighboring countries? This represents at least more than 50 billion Euro per year!

Assumptions for the Scenario 2030

The electricity grid of the future will turn diverse historical processes upside down. We assume the following in this regard for 2030 in Germany:

- *Generation will take place in the lower grid levels*. In this regard, it encompasses renewable energy sources such as wind, PV and biogas. 80 % of the generation volume in 2030 will originate from these sources. In 2050, it is supposed to even reach 100 % in Germany. Austria is pressing even harder on the "gas pedal": already by 2030, 100 % is supposed to be attained[85].
- *Generation is not plannable*. It is essentially weather-dependent and vulnerable to influential factors which require constant fine adjustment due to high generation volatility. This begins with unexpected local clouding or stormy troughs of low-pressure which are difficult to forecast, over the previous day's weather forecast for a region which turns out to be completely wrong, to winters with longer or shorter doldrum weeks.
- *Consumption will follow the generation*: If the generation is highly volatile, the consumption of electricity must be correspondingly flexibilized. This will not only have to lead to consumption-side flexibility, but rather also to the possibility of storing energy – in the short term in batteries and over the longer term, for example, in the form of gas storage devices ("power-to-gas").
- *The consumption of electricity will be higher in the future and likewise no longer plannable*. The assumption here is that, due to the increasing percentage of EVs (electric vehicles), the additional consumption will be subject to extreme fluctuations because the drivers of EVs will

[85] Study on Electricity's Future: https://mission2030.info/wp-content/uploads/2018/10/Klima-Energiestrategie_en.pdf

> connect them, for example, after 5:00 p.m. every day in order to recharge them (or send their vehicles to the countryside, like 75XBOBBYFCELL in the Prologue). Already today, all larger cities would face a problem if they tried to convert merely their bus fleet to electricity – the local grids wouldn't be able to withstand the load of the depots if all buses were recharging there overnight.

These developments will not only lead to a permanent need for fine-grade control, but rather to an overburdening of the grids because they are not designed for larger loads. Now, one could expand these grids (both transmission and distribution grids) for 50 billion Euro or more[86] – or attempt to save a portion thereof by using them more efficiently and by alleviating generation spikes and generation losses as locally as possible (see project NEW 4.0 in Chapter 6.2).

In the following scenarios, today's regulatory restrictions are not considered. This is a strong assumption because almost everything in the energy industry is regulated: The composition of the retail electricity prices, the standards for electricity traders, the reporting of transactions to the regulatory authority as well as a seemingly infinite number of processes, data formats and protocols between the various market roles – actually, the entire industry-wide Yin-Yang-Yong. We will simply ignore all of this for now in order to see whether the energy transition can't also be more efficiently implemented if regulations do not compel the market participants to make imperfect allocations.

The rough assumption is that electricity trading must take into consideration the topology of the distribution networks in order to not be led astray by the illusion of the copperplate. Whoever does not like this may otherwise expand the European network infrastructure for many times over the aforementioned 50 billions for the copperplate (which will still nonetheless be hole-ridden) – because a percentage of 80 % in renewable generation is planned over the long term for other European regions as well.

In this sense, an incentive is supposed to be created – particularly in congestion situations – to locally consume electricity which is locally generated (see project ETIBLOGG in Chapter 6.3). Ideally, each local grid would then be self-sufficient. However, this would be extremely inefficient because, in this

[86] https://www.amprion.net/Press/Press-Detail-Page_17984.html

extreme case, any form of exchange with the rest of the grid world would not be intended. Instead, electricity is consumed where it is generated – namely in the household. This works only in the summer and only with sunshine. But in any case, self-consumption is worthwhile at costs of a few cents per kilowatt hour because externally-procured electricity costs up to 30 cents today including all levies and taxes. Self-consumption can still be expanded through the installation of a battery and, in accordance with the German Tenants' Electricity Act ("Mieterstromgesetz"), the supplying of house or housing complex inhabitants at privately-set conditions will be possible – a win/win/lose situation for landlords/tenants/the tax income received by the government.

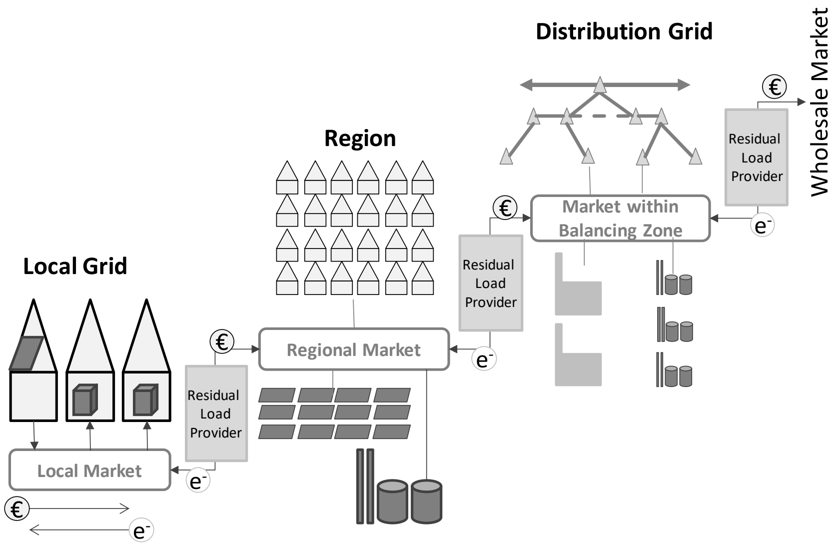

Figure 60: Bottom-up electricity supply as a coupled, market-driven control loop

Surplus electricity is delivered to the local grid and could be purchased by consumers who do not have PV units at their disposal or, to third parties who purchase the electricity if it is reduced below market price, in order to store it for use later when prices are higher. Another scenario could be when the surplus is delivered to the next-higher grid level where the game continues on. The big question is thus: Can "electricity supply" be considered to be a control loop in which only a few signals suffice in order to sensibly design the allocation of generation and consumption both location-wise and time-wise?

Figure 60, shows several focus points whereby one can create a decentralized marketplace for the trading of electricity:

- On the *wholesale* trading level, the "Enerchain" Project is a global pioneer. In this case, a consortium of prominent energy companies has been formed in order to also trade energy in the future in a decentralized manner via the blockchain. Detailed information in this regard can be found in Chapter 6.1.
- On the medium level, already today it encompasses the trading of flexibility via a smart market. This topic has been handled thoroughly in the USEF White Paper on Flexibility Services[87]. In Chapter 6.2, additional information can be found regarding the blockchain-based approaches of smart markets as a part of project NEW 4.0.
- On the lowest level, P2P trading takes place between the prosumers and the consumers in the local grid. Nowadays there are probably hundreds of start-ups, research projects and internal projects of utilities and electricity suppliers bustling about in this segment. Chapter 6.3 discusses this scenario in somewhat more detail and describes ETIBLOGG – a blockchain-based project for P2P trading in the neighborhood.

Does it make sense that every single generator, consumer and grid operator is a market participant? Can one leave it up to the market to control the electricity supply? This is a rather wide-ranging assumption and it still requires a lot of research and simulation projects until one can make a realistically reliable statement in this regard – but one thing is for certain: With or without the market, the data volume to be exchanged on all levels will be many times the current volume. Before we follow up on the model, the costs to be expected for the market participants in Scenario 2030 should be more precisely understood.

[87] USEF White Paper on "Energy and Flexibility Services for Citizens Energy Communities", https://www.nweurope.eu/media/6768/usef-white-paper-energy-and-flexibility-services-for-citizens-energy-communities-final-cm.pdf

Assumptions regarding the cost structure in 2030

In 2030 the investment per kilowatt of generation capacity will reside at less than 500 Euro (today large-scale wind units can already be installed with an investment of below 1,000 Euro/kW). Over the long term, large and medium unit operators will offer their electricity in wholesale trading for 4-6 cents/kWh – this will lie in the range of the wholesale trading price in 2018. On the photovoltaic side, large power plants are already in use these days in the United Arab Emirates and in other countries in the region. Dubai leads with 800 MW in generation output in 2018 and an expansion up to 5 GW in 2030[88]. As such, the operator will be able to safeguard delivery prices of 2.99 US cents per kWh. Of course, we admittedly do not all live in Dubai with more than 2000 kWh/kWp[89] per year, so one should realistically be able to calculate twice the price (5 Euro cents / kWh) as the basis for 2030 in the middle of Europe.

In 2030, battery storage devices will cost the end consumer only 200 Euro/kWh.[90] Because Tesla already produces batteries for less than 300 USD/kWh, this assumption for 2030 is not unrealistic. In Germany, the installed renewable generation capacity could possibly reach 230 GW from which, as a general rule, only a small portion of that will actually be used by the end consumers. The rest will be made available directly or indirectly in order to generate hydrogen via electrolysis. This will then be made available for cars like 75XBOBBYFCELL, in exceptional high demand situations and for the winter months as a reserve capacity.

In 2030, the incentive for supplying locally will be provided by dynamic grid usage fees from the grid operators which today have a nationwide levelled surcharge of 6-7 cents net per kWh on top of the wholesale price. However, this could be differentiated in the future based upon the grid level: An electricity delivery within the local grid may only cost 2 cents, within the distribution grid area 6 cents and beyond its boundaries perhaps even 10 cents. The price incentive is to also consume locally with nearby generation and,

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88 https://www.dewa.gov.ae/en/about-dewa/news-and-media/press-and-news/latest-news/2016/06/dewa-announces-selected-bidder

89 kWp = kilowatt peak, i.e., the maximum physical generation capacity.

90 Bloomberg, "Electric Vehicles to be 35% of Global New Car Sales by 2040 - Bloomberg New Energy Finance". http://about.bnef.com/press-releases/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/.

over the long term, to establish oneself with one's own generation unit where the consumers are also actually located. Or, conversely, as the consumer, to settle there where the electricity is cheap – one need only think on the bumper-to-bumper traffic in the Prologue…

The grid operators, as particularly highly-regulated undertakings, are only able to earn a certain percentage on their amount of profits. Accordingly, it is necessary for them to pass on their costs in the form of grid usage fees to the electricity consumers. That is to say, in Scenario 2030, the current 7 cents would also have to be tolerated, but just not in the same amount per kWh.

4.4.1 Usage of a smart market

The following graphic shows a distribution network in a normal state. In the jargon, one calls this the green traffic light phase. The network landscape equates to a copperplate whereby there is always sufficient line capacity available regardless of the direction and the distance. At no point does a bottleneck occur. In this regard, it is left up to the market to regulate the procurement of electricity between supply and demand.

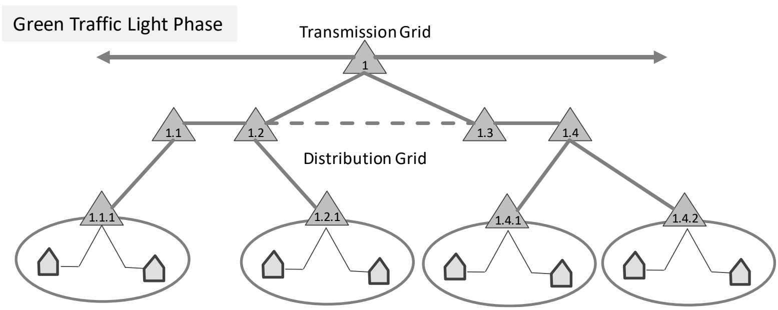


Figure 61: Green traffic light phase within the distribution grid

However, as with a traffic light, the network state will switch to yellow if caution is required: Now congestions are becoming noticeable and not every originally-planned electricity delivery can still be transported completely via the network because load peaks begin reaching the grid capacity limits. Figure 62 shows congestion on the medium grid level. It is now the responsibility of the distribution grid operator to intervene in a "grid-supporting" manner. Grid-supporting means in this case that the market can no longer evolve entirely on its own. However, it depends on the design of the market model regarding how intensely the market is supposed to be restricted. Based on the necessity for grid-support, the DSO will accordingly control consumers and generators who provide flexibility. One then calls this *demand side management* and *supply side management*. The market only takes effect when providers offer flexibility with their respective prices to the DSO during a bidding phase (e.g. on the previous day).

At the time that the congestion occurs, then, beginning with the ones with the most attractive price, the flexibility suppliers will be regulated upwards or downwards in their production or their consumption.

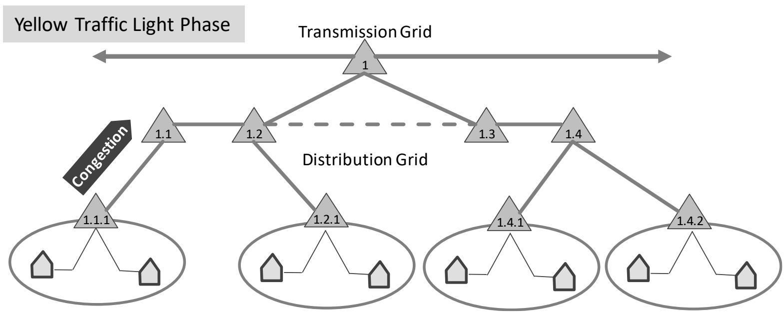


Figure 62: Yellow traffic light phase in the distribution grid

However, it is also conceivable that, in the case of congestion situations, more incentives will be created for local consumption or the deactivation of generation units if the grid usage fee can also fluctuate timewise. Then the local market price would be based on supply and demand – plus an adjusted "toll" which promotes or prevents grid usage. Normally, this would perhaps be approx. 2 cents within the local grid. If, however, delivery is supposed to be made which exceeds the capacity in congestion situations, the price could reach 10 cents or more. That is to say, supplying electricity beyond the local network then makes practically no sense. Conversely, the local price may be greatly reduced because, before the generators turn off their units, they will perhaps also sell the electricity for only one cent to their neighbors or even gift it because variable costs hardly exist. On the other hand, if the grid is in the green phase, electricity can also be delivered only for one cent in tolls to higher network levels if the producer can then make a contribution there to alleviate other congestions.

One can envision transformers between the network grid and also lines as toll zones which respectively collect their own toll for the transmission of electricity. Whoever wants to could thus deliver a kWh from the northern part of the country to the southern part which will then cost 4 cents there as a generation price plus 9 cents as a grid toll – plus any additional levies, taxes, fees, etc. This would obviously not be attractive in 2030, so decentralization is a key requirement.

Figure 63 shows this toll model in the "relaxed" phase and in the congestion phase. In the first case, the grid usage fee within the local network is only two cents so that electricity deliveries within the neighborhood are very attractive for the consumer. Deliveries via higher grid levels are correspondingly taxed a higher toll so that it is indeed possible, but less attractive, to deliver within a distribution grid across longer route sections. Conversely, in the yellow traffic light phase, a congestion has emerged at a higher grid level. The toll has increased here by an additional 9 cents. A delivery must now include these transport costs which have increased substantially. So, it is more attractive to deliver below or above the congestion point or also in the opposite direction as this is even incentivized by a reduction of 5 cents (congestions are asymmetrical).

4.4.2 The invisible hand of the market

If it is no longer attractive in the depicted congestion situation to deliver electricity trans-regionally, then the generator has only the choice left to turn off his unit or to sell the electricity locally at much, much cheaper prices. A cold storage warehouse nearby will thankfully purchase it if it only costs half-price, for example (incl. all taxes/levies/fees).

In a model, which is based on demand-side management, it might not be the most market-oriented process to allow distribution grid operators to unilaterally decide at what conditions they are supposed to request positive or negative flexibility from the participants. Instead, DSOs could take the role of a moderator who provides the market with congestion signals which then indirectly result in alleviating actions in the case of a more market-oriented model.

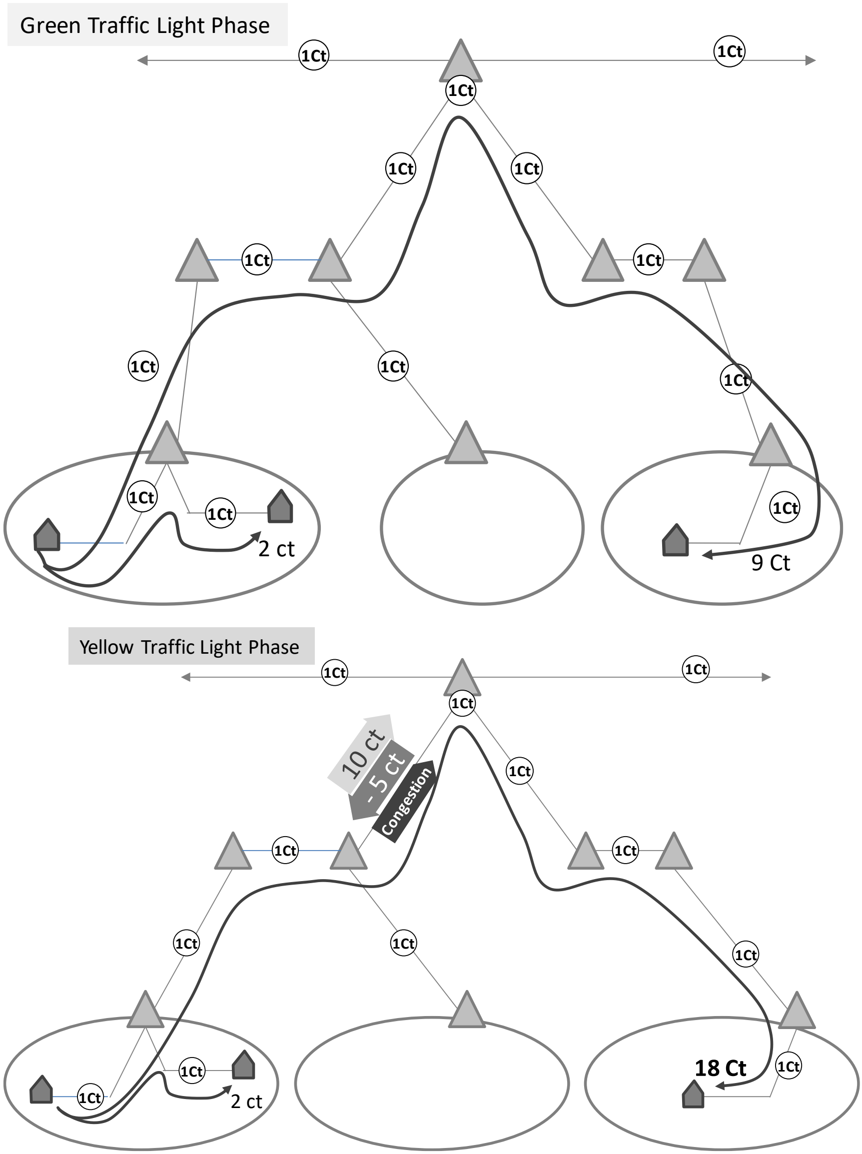


Figure 63: Toll model in the green and the yellow traffic light phases

These ideas make sense only if the congestion signal also has significant impact on the sales and the costs of the participants. Today, the wholesale trading price – including electricity sales – is approx. 6 cents. The discrepancy between this and the gross electricity costs of 30 cents consists of taxes/levies/fees which are quite high. Consequentially, a change in the grid usage fee (currently: 7 cents) will hardly have an influence on the gross price. Scenario 2030[91] would function ideally if

- the variable costs of the electricity generation go down to almost zero (as is the case with PV and wind),
- the net prices per kWh could fluctuate between 0 and 10 cents – depending upon the weather, demand and load situation, and other factors,
- the levy for the subsidization of renewables (as imposed by the German renewable energy law) is eliminated,
- grid usage fees are dynamized following the above mechanism, and
- other levies would be incorporated into the 19 % German VAT. the leverage effect from the fluctuation of net prices would be so high that it makes sense to trade locally and even install as a generator among the consumers or vice versa.

If the above occurred, then the neighborhood's electricity would cost only a few cents and, at the current price, also be supplied trans-regionally. The incentive would also lie in the self-supplying and increased resiliency of regions. The ability to locally alleviate congestion situations would be substantially higher than today and the incentive to locally adapt generation and consumption to each other would be economically incentivized.

4.4.3 Trading parties on the electricity market in 2030

Traders upon the part of the prosumers and the consumers are not persons, but rather algorithms in the control systems of the respective generators and consumers. As is the case today with a hybrid vehicle, a control algorithm will decide whether the battery is charged with generated electricity or whether it is supposed to be discharged in order to support the motor.

[91] Actually, it would be closer to 2040 as the result of the EEG levy which would only then have lapsed completely.

Similarly, the local trading software of the unit controlling system will make decisions upon a minute-by-minute basis in regards to whether electricity is supposed to be stored or sold via the grid. If this is the case, an offer is placed on the regional market for electricity deliveries.

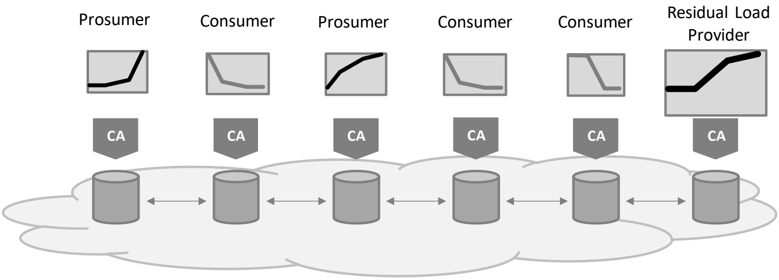


Figure 64: Various supply and demand curves on the smart market

Each prosumer is represented by an automated energy agent. The agent decides whether it makes more sense to sell surplus energy that has been generated, to store it, to locally consume it, or to procure additional energy from the grid. The optimization goal can change at any time as the result of internal or external parameters and forecasts: For example, it could be the case that the electric vehicle has just been connected or that the stove was turned on. This would be a new situation to which the prosumer's trade agent adapts on short notice by altering its behavior based upon the policy preferred by the prosumer – just like accelerating or breaking in a hybrid vehicle (see also in this regard project ETIBLOGG in Chapter 6.3).

However, the critical question is where the signal for the agents is supposed to come from, whether and at what price they are supposed to buy or sell? In order to do this, a marketplace is once again required – as already described above in conjunction with the wholesale trading, but nonetheless infinitely more short-term and fully-automated. Local energy agents from the DSO's region trade on this market, in addition to trans-regional traders, also called *residual load providers*. Influenced by the wind and the sun, the agent's sale offers within a region are always just slightly differentiated. Moreover, the quantities traded there are rather small. However, the residual load providers can request or offer much larger quantities because the requirements in various regions can substantially deviate from each other. For example, they can be quite a bit more or less windy or have much higher industrial demand.

In contrast to the situation today, in Scenario 2030, there will be no more aggregators who bundle small generators in a hierarchical fashion. Instead, the latter will have liberated themselves as independent players on the local or regional markets. Aggregators will be replaced by residual load providers, which balance supply and demand back-to-back in between the regional and trans-regional markets. They act as participants in the regional market alongside the local participants and no longer above them.

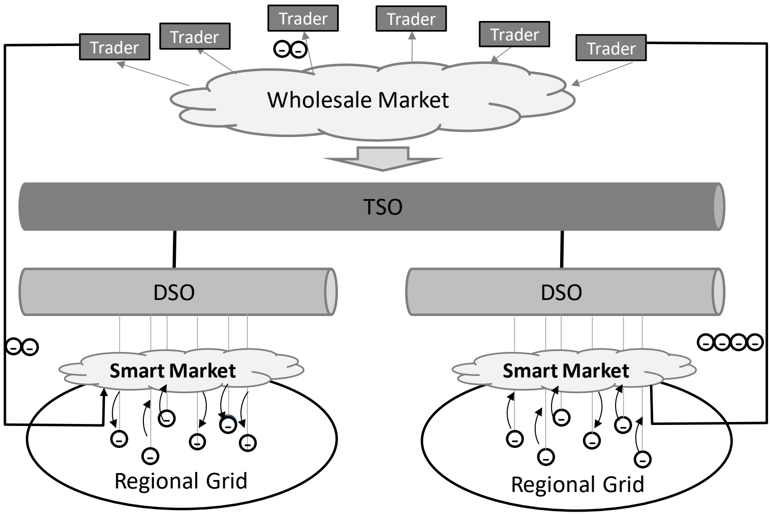


Figure 65: Regional smart markets vs. wholesale market

Situations with high generation automatically lead to electricity prices close to zero cents / kWh. In 2030, there may be no more negative prices because the generators themselves may possibly reduce the output of their units. However, zero cents are realistic because the operation of the unit will create only negligible running costs. Nevertheless, power supply at minimal prices is once again attractive to gas generators (which transform power to gas) who produce hydrogen or methane at low cost during surplus phases. One may only think about the situation earlier mentioned on Sunday, May 8, 2016: In this case, up to 13 GW of surplus electricity was generated over several hours' time. This can be transformed and stored as hydrogen, then fed into the corresponding reserve capacity of gas power plants which can then be used for dark, windless winter hours and other "doldrum" periods.

Figure 66 shows the interplay between automated market players who are each pursuing their own optimization goal, possess information regarding their planned consumption or planned generation as well as forecasts regarding prices and the weather. The information at current market prices in the figure is still being obtained from the EPEX Spot exchange. However, in Scenario 2030, the price may be based upon regional parameters – from the local weather forecast above all.

The first characteristic from Figure 66 shows the actual price forecast for September 23, 2016:

- At night, the prices are low because the consumption is also low.
- At mid-day, the prices are low as well because the PV production in this case delivers a maximum amount of electricity.
- Conversely, in the morning and in the evening, the PV production is low while consumption is at a medium level, so prices are higher.

One aspect is missing in the curve for Scenario 2030: One would naturally still have to include the charging of the electric vehicles overnight in the calculations.

Some market players, e.g. the battery storage devices, behave in a rather straightforward way on the local market: If prices are low, it charges itself; if prices are high, it discharges. Others, like the electrolyzers, are even more clever: They follow a given plan (e.g. to convert a MWh of electricity into hydrogen), but can adapt themselves to the forecast and perform load shifts. That is to say, they attempt to allocate their work across the 24 hours so that they can perform the main portion of their work at the lowest possible prices. One can even expect that an office building will know its usage profile and thus intelligently plan its consumption throughout the day.

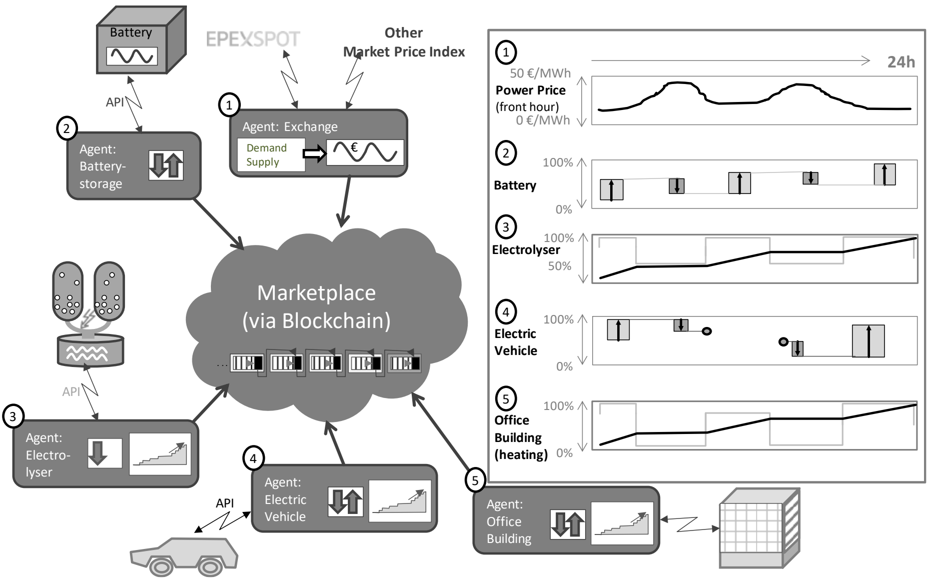
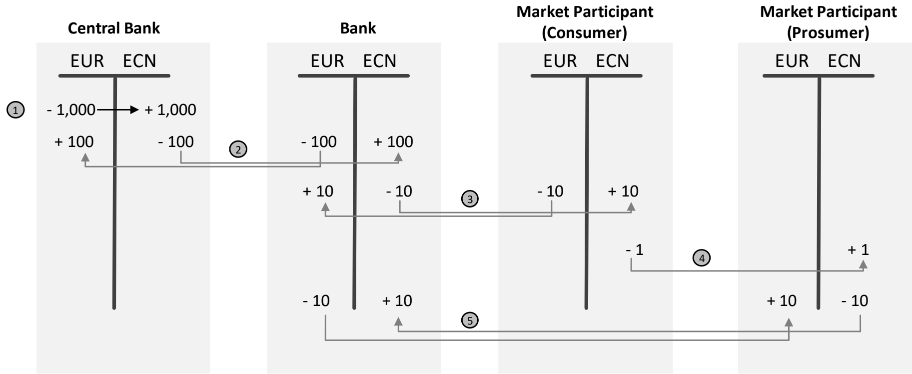


Figure 66: Software agents trade on a local flexibility market

For the trading of electricity, each participant has an Enercoin account. This is the token currency for electricity. Whoever wants to buy electricity needs to convert Euros into Enercoins via a Coin Providing Authority. As already mentioned above, this should be possible without large transaction cost expenditures. The Coin Providing Authority supports the exchange by booking from the Euro account to the Enercoin account of the participant or also through exchanges via which the Enercoins can be directly exchanged for other currencies apart from the Euro. The 1:1 pegging to the Euro may disappoint libertarian proponents of free cryptocurrencies, but it is nonetheless easier to value the fluctuating price of the commodity "electricity" in a currency firmly anchored to a fiat currency than to have to track two exchange rates (Enercoins against the Euro and then kWh price against the Enercoin). Perhaps, it is even advisable to avoid any designation which deviates from "Euro" because, de facto, there is a corresponding amount of Euro "frozen" by the coin providing authority in order to use Enercoins.

Because the issuance of Enercoins coincides with the fact that a corresponding Euro amount will be pulled from circulation, this excludes the possibility of creating money out of thin air. Nonetheless, one can envision that the central bank will conduct a complex series of calculations in order to determine which "money supply" of Enercoins is required in order to provide the required liquidity for the cycle comprised of electricity production, trading and consumption. Banks can procure Enercoins for themselves from the central bank up to the amount of the Enercoin money supply.[92]



1. Initial generation of the Enercoin money supply (if required, sporadic adaptation of the money supply to the demand for Enercoins)
2. Commercial banks exchange Euro for Enercoins at the central bank
3. Market participants exchange Euro for Enercoins at the commercial banks for transaction cash management purposes
4. Market participants use Enercoins in order to buy and sell electricity
5. As required, market participants redeem Enercoins from a bank once again for Euro

Figure 67: The cycle of Enercoins

If the demand for Enercoins increases, then the central bank can affect a transfer between the Euro and Enercoin by booking transfers from Euro accounts to its Enercoin account. The central bank would thus act as the single authority which could alter the aggregate of all Enercoin balances within the Enercoin world. As participants on the market for Enercoins, banks offer to exchange "Euro for Enercoins" to their customers for a fee. This is an automated process which is implemented competitively at low

[92] See the literature on central bank digital currencies (CBDC), e.g., this report published by the Bank for International Settlements: https://www.bis.org/cpmi/publ/d174.pdf

cost. If a participant has covered himself with Enercoins, his energy agent can trade and pay for electricity in very small units without significant transaction costs.

The transfer of an Enercoin amount is done by inputting signed bookings between the buyer and the seller into the blockchain. The overall money supply is broken down into the accounts of the central bank, the commercial banks, and the participants in the energy market.

The transaction demand for Enercoins may initially be created by the consumers and then go over to the generators during the course of the trading. They then change back Enercoins once again into Euro via their bank. However, one can also envision that the roles of the "bank" and the "wholesale trader" will merge, i.e. the Enercoins received from electricity customers will be changed back by these customers once again into Euro.

In Scenario 2030, one can assume that the aforementioned energy market is almost perfect, i.e. transparency exists regarding supply and demand and the behavior of both sides is fundamentally known to the other participants. Because the players on a local market are exposed to similar framework conditions (prices for generator and storage technology, same weather conditions, etc.), local and trans-regional parameters determine the local market price.

An example in this regard: Under normal circumstances, PV prosumers in Bavaria in southern Germany would sell their neighbors electricity at a price of gross 5 cents/kWh during the daytime and at 10 cents at night (from their batteries). However, there is a substantially-increased demand trans-regionally because, in northern Germany, the doldrums prevail and, consequentially, the northern consumption can no longer be covered by the southern producers. Suddenly, the Bavarian trade agents for the PV units increase their prices over the short-term to 15 cents gross because they – instead of feeding their solar power into batteries or power-to-gas units – can now deliver them trans-regionally with a higher profit. This increase in profit is revealed to all Bavarian suppliers at once because they all use more or less the same price curves for their offer. In addition, an additional 10 cents as a grid usage fee is incurred due to the trans-regional delivery. After the market price in the south has risen in this manner to approx. 25 cents, it will also become profitable for the operators of gas power plants at higher grid levels to likewise produce electricity. If the windlessness then continues overnight, this will lead to an additional increase in the market price to 55 cents/kWh. Even the last CHP units now also participate in the market and generate potentially 30 cents as a contribution margin per generated kWh for their owner. If required, Norwegian operators of hydropower plants may also likewise supply additional electricity. At 55 cents/kWh (550 Euro/MWh), even the operation of a modern gas power plant may be profitable even if it runs only one month per year.

For the consumers, this means on average, for example, throughout the year, that they will procure their electricity for six sunny months at minimal costs from the local grid in their neighborhood (e.g. for 15 cents gross) – these are mainly grid usage fees and levies. For five months, the electricity will cost 15-30 cents (among others, from trans-regional or non-renewable production) and, for one month, they will pay scarcity prices in the range of 30 – 60 cents (gas power plants, CHPs, etc.). On an annual average, this then amounts to 18-20 cents/kWh – a value with which generators, consumers and grid operators in 2030 could probably live quite well.

It is important to still state that the classical electricity sales will naturally continue to exist, i.e. a consumer will conclude a supply contract with a supplier in order to, for example, be supplied for a year at a fixed price per kWh. This may even be valid for many of the private and industrial customers because they cannot generate electricity. In this regard, the supplier becomes the residual load supplier because the residual load needs to always be available to close the discrepancy between locally-generated electricity and actually required electricity. This requires that it has a much more flexible generation capacity. In this regard, it may be acceptable that the price for their "electricity of last resort" which they must always be able to deliver, will be higher than the local generation costs.

The separation of energy trading into regional markets coincides with the formation of localized price areas ("nodal pricing") in which market prices can deviate from each other. In northern Germany which has an excessively large number of wind power plants, the price may be lower than in southern Germany where the consumption is higher and thus the price is also higher. This separation could also be further broken down so that, for example, hundreds of grid-location specific prices are created for which delivery is internally cheaper compared to externally. Through flexible grid usage fees, the incentive is then created to invest long-term in energy production where consumption and prices are higher. Incidentally, this is historically quite normal behavior which is why the energy-intensive industries in the 19th century settled in the Rhine / Ruhr region in Germany above all else because they would find themselves in close proximity to the energy source of coal.

4.5 Usage of the blockchain in energy markets

But why this detailed analysis of pricing in regional electricity networks? With regards to the usage of the blockchain, the question arises regarding whether, in the case of the depicted scenario of regional generation, the generated quantities and their prices have to be a secret at all? If it is known in the village how many kW of PV generation capacity and battery storage a PV panel owner has and if the behavioral patterns of the electricity agents (due to the same CAPEX and OPEX structure[93]) are almost identical, then the profit from the production of electricity is no longer a secret. If the PV panel owner sells on average 10 kilowatts from his production for 6 cents, then this amounts to perhaps 600 Euro in sales per year (more than 1000 kWh cannot be harvested per kWp in the latitudes of middle Europe). Even in the case of a quantity ten times bigger, it always still entails a sideline business which necessitates no secrecy. Can the blockchain of 2030 possibly be designed to be very lean because it foregoes features such as anonymity and encryption of transaction details? This would very closely approach the application profile of the B2B blockchain.[94]

Besides the core business of energy trading, additional services are gradually being created which will also be traded in the Enercoin world so that it will be quite normal for the user to not only monitor his Euro account balance, but rather also his Enercoin account balance. Through the 1:1 peg to the Euro, revenues and outlays can also be integrated directly into the corresponding software for accounting and tax purposes.

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[93] CAPEX: Capital expenses, OPEX: operational expenses.

[94] Conversely, on the consumer side, the situation appears to be much more difficult because, in accordance with the data protection laws – particularly after the GDPR became effective in 2018 consumer data is even much more strongly protected.

The very wide-ranging "Scenario 2030" described above can still be re-thought in further directions:

- *Do we really need a central bank* in order to bring Enercoins into circulation? Probably not. The task of managing an Enercoin money supply could also be fulfilled by a private company as the issuer of the currency. This would combine the role of the central bank and a commercial coin providing authority. It would amass a higher amount of Euro for the issuance of a corresponding amount of Enercoins. The Enercoin money supply would be created from the exchange transactions between the issuer and the market participants. A controlling of the money supply with regards to a target value would not be required. However, the issuer would have to be a trustworthy third party so that market participants could rely on the usage of Enercoins or a cryptocurrency like Libra. In the scenario of local markets, besides the banks and the wholesale traders, there are, for example, TSOs or DSOs as the few major players who participate in energy markets. In the future, perhaps these will also gain importance in addition to the physical transmission and distribution of electricity?
- *Are multiple issuers of Enercoins conceivable?* This depends greatly on the design of the blockchain. While, in the case of Bitcoin, the mining – thus the money creation – is restricted through costly PoW mechanisms, one could, if collective trust exists, also assign the responsibility for the issuance of Enercoins to a group of organizations which operate the blockchain as a consortium, similar to what Facebook has initiated with regards to Libra.
- *Do we really need the Euro as a reference currency?* Theoretically, a private currency "Enercoin" could be decoupled from the Euro. Then, an exchange rate risk could also come into play. There is also sufficient literature from the Austrian School of Economics which consequently states that a private currency should compete with the central bank's legal tender in order to discipline the latter through a quality competition. More detailed information in this regard can, for example, be found in Hayek's "Denationalization of the Money" [Haye77]. It would also be conceivable that we will have a competition of private currencies from which the transaction partners can pick one out to use in order to book their payments. Although this may be realistic and sensible from a macroeconomic

perspective, the controlling of budgets and the hedging of exchange rates could nonetheless overburden the persons or agents participating in energy trading. Conclusion: Better do not use a freely-fluctuating cryptocurrency for energy transactions.

- *Why not immediately transfer the legal tender to the blockchain?* This would be the most radical variant whereby the Euro (or CHF, GBP, USD) itself will simply be "blockchainized" as central bank digital currency (CBDC). Then the trading of goods of all kinds would be just as efficient as described above for the trading of electricity[95]. However, this would presumably be accepted only if the blockchain guarantees a certain degree of pseudonymity like we are familiar with today with Bitcoin. And doubt remains regarding whether a blockchain technology can be so high-performing within the foreseeable future that it can tolerate the load of reliably and promptly booking any arbitrary transaction of the combined European economies with more than 500 million inhabitants – by now it is obvious that the hierarchization of blockchains depicted in Chapter 3.4 will be required.

There are still many additional points to be clarified until Scenario 2030 can be realized. In the discussion with economists, for example, the following question has arisen: How is one supposed to handle a market crash or a market failure in the flexibility market? If, during such phases, no defined market price is made available and, over the short-term, no electricity can be traded – how will the deliveries still be made? Questions upon questions which we can neither answer today nor are even yet familiar with overall.

A blockchain infrastructure for the energy trading of the future which is supposed to fulfil the aforementioned requirements must be able to process mass data in quite different dimensions. Presumably, there are some 10,000 transactions per second which would have to be booked throughout Europe. If, however, the largest portion of the transactions takes place in subgrids, then the measures of "divide and conquer" described in Chapter 3.4 need to

[95] In fact, some central banks are experimenting with this idea, e.g. the Bank of England: http://www.telegraph.co.uk/news/2017/12/30/bank-england-plots-bitcoin-style-digital-currency/.
And Dubai also wants to bring a cryptocurrency into circulation for the United Arab Emirates: https://cointelegraph.com/news/dubai-will-issue-first-ever-state-cryptocurrency.

be applied. Such blockchains would then have to be organized along the grid hierarchy. In this manner, within the region, the transactions of several million grid connections of a DSO would certainly be processable. The TSO would then read out the data from the DSO in its balancing zone as well as the overall data in order to gain a real-time profile of the grid state and the expected deliveries. It would also be conceivable that the DSO will filter these details locally and report only balanced volumes to the TSO.

As stated, the aforementioned is just a scenario. There are still some years to go until we reach 2030, but it can definitely be useful to discuss future usage possibilities so that one has a vision of the refinement of blockchain technologies at which the developers at the affected companies can try to target.

As the preliminary step of Scenario 2030, it would be interesting to half-way develop an island model whereby a blockchain-based electricity marketplace can be tested with a manageable number of participants. Taken literally, there are actually several islands which are available for such a project: The Isle of Man has, for example, 80,000 inhabitants, Ibiza 135,000, Mallorca 900,000 and Cyprus 1.1 million (both parts). If there are several thousand prosumers there to be market participants, then the aforementioned Scenario 2030 could perhaps indeed be done on a small scale within a few years. Even the behavioral patterns of fully-automated markets could also be observed well with this population of participants. During the course of model projects, providers could try out the development of peer-to-peer marketplaces and the agents trading on them.